State of California
Environmental Protection Agency
Department of Toxic Substances Control

SUPPLEMENTAL GUIDANCE FOR HUMAN HEALTH MULTIMEDIA RISK ASSESSMENTS OF HAZARDOUS WASTE SITES AND PERMITTED FACILITIES

Prepared by
The Office of Scientific Affairs

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FOREWORD

The California Department of Toxic Substances Control (DTSC), within the California Environmental Protection Agency, has the responsibility of managing the State's hazardous waste program to protect public health and the environment. The duties of the Office of Scientific Affairs (OSA) include providing scientific assistance in the areas of toxicology, risk and environmental assessment, training, and guidance. Part of this assistance and guidance is the preparation of regulations, scientific guidance documents, and recommended procedures for use by regional staff, local governmental agencies, or responsible parties and their contractors in the characterization and mitigation of hazardous waste sites and permitted facilities (also referred to as hazardous substances release sites; toxic waste sites; treatment, storage, disposal facilities).

A quantitative human health risk assessment is an integral part of the site mitigation process for hazardous waste sites and may also be required before a permit can be issued to a treatment, storage and/or disposal facility. These assessments eventually form a part of the public record and provide the basis for the justification of decisions taken to protect the public health against significant risk as well as providing information about the nature and magnitude of the potential health risks associated with the site or facility.

The U.S. Environmental Protection Agency (US EPA) has published a manual which provides detailed instructions for performing human health risk assessments (Risk Assessment Guidance for Superfund, Volume I, Human Health Evaluation Manual (Part A), Interim Final (EPA/540/1-89/002, December 1989 (HHEM)). In addition, the US EPA Office of Solid Waste and Emergency Response (OSWER) issues directives from time to time which clarify or provide further guidance. Multimedia human health risk assessments prepared for sites or facilities over which the DTSC has jurisdiction must conform to the guidance in the HHEM and OSWER directives.

This DTSC guidance manual supplements the HHEM and OSWER directives by providing recommendations on specific technical or scientific issues that may be encountered when preparing multimedia risk assessment reports for submittal and review by the DTSC.

The toxicologists within the OSA who prepared these scientific guidance documents or participated in their review include:

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Chapters 3, Documentation and Assumptions Used in the Decision to Include and Exclude Pathways, and 4, Guidelines for the Documentation of Methodologies, Justification, Input, Assumptions, Limitations, and Output for Exposure Models, have been removed from this guidance and is replaced by the Technical Reports describing the basis of the CalTOX model.

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ORDERING INFORMATION

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OFFICE OF THE SCIENCE ADVISOR GUIDANCE

CHAPTER 1

DEFAULT EXPOSURE PARAMETERS

ABSTRACT

This guidance document lists some exposure parameters which may be used as default values in a human health risk assessment if no site-specific information exists for the parameter in question. These default exposure parameters are to be used for calculating reasonable maximum exposure (RME) estimates.

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1 INTRODUCTION

1.1 PURPOSE

This document provides guidance to the Department of Toxic Substances Control (DTSC) staff, responsible parties, and other interested parties on the acceptable default exposure parameters to be used when estimating reasonable maximum exposure (RME) intake values at hazardous waste sites or permitted facilities. The listing of these exposure parameters is intended to aid responsible parties and their contractors in preparing risk assessments and DTSC project managers and the public in evaluating risk assessments.

1.2 APPLICATION

The exposure parameters listed here should be used when no site-specific data are available or when there is no concensus on the appropriate parameter value. The values listed in Table 1 are excerpted from the U. S. Environmental Protection Agency (US EPA), Office of Solid Waste and Emergency Response (OSWER) Directive 9285.6-03 (March 25, 1991). The values listed in Table 2 are dermal exposure factors agreed upon by the DTSC as appropriate for use as upper-end values in a residential exposure scenario for a Preliminary Endangerment Assessment (PEA) and as RME in a human health risk assessment. These dermal values are either directly from or consistent with values listed in US EPA Dermal Exposure Assessment: Principles and Applications, Interim Report (1992).

1.3 LIMITATIONS

The DTSC encourages the use of scientifically justified site-specific data whenever possible in order to more accurately estimate the health risks associated with a site or facility. The listed exposure parameter values should be used when such data are not available or when calculating reasonable maximum exposure values.

2 DEFAULT EXPOSURE PARAMETERS[a]

2.1 TABLE 1, STANDARD DEFAULT EXPOSURE FACTORS[b]

Land Use	Exposure Pathway[c]	Daily Intake Rate	Exposure Frequency	Exposure Duration	Body Weight
Residential	Ingestion of Potable Water	2 liters	350 days/year	30 years	70 kg
	Ingestion of Soil and Dust	200 mg (child) 100 mg (adult)	350 days/year	6 years 24 years	15 kg (child) 70 kg (adult)
	Inhalation of Contaminants	20 cu.m (total) 15 cu.m (indoor)	350 days/year	30 years	70 kg
Commercial/ Industrial	Ingestion of Potable Water	1 liter	250 days/year	25 years	70 kg
	Ingestion of Soil and Dust	50 mg	250 days/year	25 years	70 kg
	Inhalation of Contaminants	20 cu.m/workday	250 days/year	25 years	70 kg
Agricultural	Ingestion of Potable Water	2 liters	350 days/year	30 years	70 kg
	Ingestion of Soil and Dust	200 mg (child) 100 mg (adult)	350 days/year	6 years 24 years	15 kg (child) 70 kg (adult)

	Inhalation of Contaminants	20 cu.m (total) 15 cu.m (indoor)	350 days/year	30 years	70 kg
	Consumption of Homegrown Produce	42 g (fruit) 80 g (vegetable)	350 days/year	30 years	70 kg
Recreational	Consumption of Locally Caught Fish	54 g	350 days/year	30 years	70 kg

[a] From U.S. EPA OSWER Directive 9285.6-03, March 25, 1991, Human Health Evaluation Manual, Supplemental Guidance, Standard Default Exposure Factors.

[b] Factors presented are those that should generally be used to assess exposures associated with a designated land use. Site-specific data may warrant deviation from these values; however, use of alternate values should be justified and documented in the risk assessment report.

[c] Listed pathways may not be relevant for all sites and other exposure pathways may need to be evaluated due to site conditions.

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2.2 TABLE 2, DERMAL EXPOSURE FACTORS

Skin surface area exposed (SA), cm^2/day:

Adult - 5,800 (head, hands, forearms, lower legs) for adults (US EPA, 1992)
Child - 2,000 (head, hands, forearms, lower legs) for age 1 to 6 years, (US EPA, 1992).

Exposure frequency (EF), d/year:

Child - 7 events/week, 350 days/year for age 1 to 6 years or 350 d/year.
Adult - 2 events/week, 350 days/year for age 7 to 31 years or 100 d/year.

Note: These EF values are based on DTSC best professional judgment, and are compatible with US EPA, 1992.

Soil adherence factor (AF), mg/cm^2:

- 1.0 (US EPA, 1992).

WATER (showering):

Skin surface area exposed (SA), cm^2/day:

- 23,000 cm^2, upper bound, whole-body value (US EPA, 1992).

Exposure frequency (EF), d/year, and exposure time (ET), hrs./d:

- ET = 0.25 hrs/day,(15 minutes; EPA, 1992)
- EF = 350 days/year (EPA, 1991).

REFERENCES

U.S. EPA. 1991. Office of Solid Waste and Emergency Response. OSWER Directive 9285.6-03, March 25, 1991. Human Health Evaluation Manual, Supplemental Guidance: 'Standard Default Exposure Factors.'

U.S. EPA. 1992. Dermal Exposure Assessment: Principles and Applications, Interim Report. Office of Health and Environmental Assessment. EPA/600/8-91-011B.

OFFICE OF THE SCIENCE ADVISOR GUIDANCE

CHAPTER 2

USE OF SOIL CONCENTRATION DATA IN EXPOSURE ASSESSMENTS

August 1996

ABSTRACT

This is a guidance document for the Department of Toxic Substances Control (DTSC) personnel and Responsible Parties (RPs) in using concentrations of substances in exposure assessments for hazardous waste sites. Specific guidance is provided in evaluation of data quality, interpretation of results, and calculation of source terms for exposure assessment. The use of statistical and spatial sampling data is discussed in the context of the calculation of the source term. Detection limits and the use of negative analytical results are discussed.

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**Use of Soil Concentration
Data in Exposure Assessments**

INTRODUCTION

PURPOSE

This is a guidance document for the Department of Toxic Substances Control (DTSC) personnel and Responsible Parties (RPs) in using concentrations of substances in exposure assessments for hazardous waste sites. It is designed to be consistent with the procedures of the U.S. Environmental Protection Agency (EPA) as described in the "Risk Assessment Guidance for Superfund, Human Health Evaluation Manual, Part A, July 1989" (HHEM) Chapters 4 through 6, and provides specific guidance on the procedures related to calculation of exposure point concentrations (EPC) of chemicals.

APPLICATION

The approach described herein is to be used to derive the soil concentration term to be used in the pathway equations which involve direct exposure to soil. It ensures that exposure assessments for hazardous waste sites will incorporate concentration estimates which are adequately protective of the public health and the environment. Estimates of chemical concentrations in soil are to be derived using these principles for all state-lead sites, but issuance of this guidance does not affect exposure assessments in progress or completed before the date of this publication.

LIMITATIONS

This document does not describe in detail the specific statistical methods for sampling, data evaluation, or modeling rate of loss or transport of chemicals at a site. Such methods are the subject of other DTSC guidance, and of several scientific publications referenced in this document. It also does not specify how soil concentration data are to be used in models describing pollutant transport, these input data requirements being model-specific.

PRINCIPLE OR THEORY

STATISTICAL SAMPLING

Statistical (random) sampling characterizes, within specified confidence limits or with a specified distribution, the contamination level of a defined unit of soil. Since it is based on probability theory, its validity depends on a lack of bias in sampling.

SPATIAL SAMPLING

Spatial (non-random) sampling characterizes the extent of contamination of soil and is typically used to characterize the spatial extent of the source or the spread of contamination from a source. Spatial sampling does not assume randomness of sampling, and does not characterize a larger unit of a medium. Descriptive statistics such as mean and standard deviation would have little or no meaning when applied to this type of data.

METHODS

DATA REQUIREMENTS.

All samples of environmental media which are intended for use in exposure assessments must be collected, handled, and analyzed properly, according to applicable DTSC and/or EPA guidance.

Environmental concentrations of chemicals must be estimated based on a limited number of samples, which generally have a wide range of concentrations. Examination of the data can often reveal the underlying sources of the variability, such as time-dependent migration or loss of chemicals. Soil samples used to characterize a hazardous waste site in support of a no-action alternative should be collected using a statistically valid sampling plan, as described by DTSC (1990a). For modeling of the contaminant concentrations in soil, air, and water, spatial distribution may be more appropriate in determining appropriate source terms for the exposure assessment than the statistical methods indicated below, which do not consider spatial distribution.

CALCULATION OF THE SOURCE TERMS.

When a statistically valid sampling plan has been followed, the EPC is ordinarily the lesser of the 95 % upper confidence limit (UCL) of the arithmetic mean of the sample values, or the maximum observed value. If a probabilistic approach is being used, concentration data are entered as a distribution. When concentrations are predicted through a distribution or dispersion model, the UCL is used in the exposure assessment. Statistical methods for analyzing log-normal distributions are described in Gilbert (1987), Parkin et al. (1988), and in a draft DTSC standard (DTSC, 1990b).

Point Sources

A chemical in soil or ground water often appears to be spreading out from a point source along a gradient. These data are well suited to a model which considers spatial distribution, and can effectively characterize contamination prior to remediation. If one chooses to apply summary statistics, it will often be appropriate to divide the site into multiple area sources instead of considering the entire site as a single source; area-weighted averaging of areas of high and low concentrations of a chemical introduces less error than averaging across the whole site, and can compensate for oversampling of heavily contaminated areas.

Statistical Validity

The statistical validity of the sampling plan is critical if a no-action alternative is proposed. For a remediation feasibility study, it is more important to characterize the extent of contamination than to assure that the samples are representative of the entire site.

Residential-use Scenarios

For residential land-use scenarios, the site-wide average concentration is less important than the maximum concentration in potential back-yard-sized areas. An appropriate-sized area for averaging sample values is 1000 ft^2, as discussed in Hadley and Sedman (1990). (The recommendation in this article to use average chemical concentrations in soil in exposure assessments is superseded by the current use of the UCL.) Surface samples or depth-weighted average concentrations down to 10 feet below the surface, whichever is greater, should be used in exposure calculations.

USE OF NEGATIVE ANALYTICAL RESULTS

Every analytical technique used to measure the concentrations of chemicals has associated limits of detection (LOD) and limits of quantitation (LOQ). A chemical that is not detected in a sample is below the LOD. A chemical that is detected but in such low amounts that its concentration cannot be accurately determined is below the LOQ. These limits vary 1) among different laboratories, 2) within a given laboratory depending on instrument maintenance, 3) among samples depending on the concentration of interfering chemicals, and 4) depending on the characteristics of the sample matrix. When a chemical is reported as not detected in a sample, the actual concentration is any value up to the LOD. When the chemical has been found in some of the samples and is not clearly spatially limited, it is assumed to exist in samples in which it was not detected (ND). The assignment of a value of one-half the LOD to all samples reported as "ND" reflects the assumption that the samples are equally likely to have any value up to the detection limit. Similarly, when the analyte is detected but not quantifiable, a value midway between the LOD and the LOQ should be assigned. If only the LOQ is reported, negative results are assumed to be from zero to the LOQ, and are assigned a value of one-half the LOQ. When the sample values above the LOQ level are log-normally distributed, it is reasonable to presume that values below the LOQ are also log-normally distributed, and the reported detection limit divided by the square root of two (1.414) should be assigned as a proxy value for negative analytical results (Hartung and Reed, 1987 and EPA, 1988).

Very High LODs or LOQs

In some cases the limit of detection or quantitation of a specific chemical in a sample will be very high due to an interfering matrix of substances. The best approach to these results is to re-analyze the samples using additional sample preparation and/or more sensitive analytical procedures. However, the distortion of the calculated value of the source term by these high detection limits is limited, because if the UCL exceeds the maximum detected value, the latter is used as the source term.

When Chemical is Limited in Distribution

When the spatial or temporal distribution of a chemical has been adequately characterized, and it is clear that the distribution of a chemical is limited in time and/or space (e.g. derived from a specific spill or source, with inadequate time to spread across the site), negative results from locations distant from where the chemical has been found may be presumed to be zero. However, the samples from uncontaminated areas should not be averaged with those from contaminated areas.

CORRECTION FOR BACKGROUND

Many substances, such as metals in soil, or nitrate in water, can be found in all samples. For these analytes it is necessary to determine what fraction of the concentrations found, if any, is due to the hazardous waste site, and what fraction represents background. "Background" refers to the average concentration of the chemical(s) in similar, nearby areas which have not been specifically contaminated and may be highly variable. It could be necessary to analyze many samples from areas near the site to adequately characterize the background. The statistics for such samples should be handled the same as for site-derived chemicals. Values that seem unreasonably high or low should be questioned, because this may indicate a methodological problem. Values obtained at other sites and by other agencies can provide worthwhile perspective. The background values are used differently, depending on whether the substance is presumed to act via a non-threshold or threshold mechanism of toxicity.

Substances Acting via non-Threshold Mechanisms

Background, pre-existing contamination does not alter the risk posed by non-threshold agents (carcinogens) associated with a waste site, calculated by the standard linear low-dose extrapolation methods. Because the Responsible Party is not obligated to clean up the background environmental concentrations of potentially toxic substances, it is reasonable to subtract such background concentrations from the measured levels.

Substances Acting via Threshold Mechanisms

For substances which have a threshold of action, the background level plus the concentration of chemical from a waste site might produce a combined exposure which exceeds the threshold for toxic effects. Subtracting the background levels before calculating risk could therefore misrepresent the threat to public health associated with the site-related contamination, resulting in the false conclusion that the site-related chemicals do not impose a risk of adverse effects on health. This should not, however, be construed as implying that the Responsible Party would be obligated to clean up the background contamination. Background levels would be considered later, as part of risk management.

SAMPLE CALCULATION

The LOD of a chemical can vary in different samples of the same medium if one chemical interferes with the analysis of another. In the following example the effect of co-contamination with toluene on xylene quantitation limits is illustrated, and the effect of these LODs on the estimated chemical concentration is shown.

	Toluene conc.	Xylene conc.	Xylene LOD	Assumed Xylene conc.[1]	Assumed Xylene conc.[2]
Sample 1	1,000	ND	10	7.1	5
Sample 2	20,000	ND	200	141	100
Sample 3	10,000	ND	200	141	100
Sample 4	30,000	500	400	500	500
Mean				197	176
UCL				446	436

[1] Assuming that the data are distributed log-normally. When the chemical was not detected, the values in this column were obtained by dividing the LOD by 1.4.

[2] Assuming that the data are distributed normally. When the chemical was not detected, the values in this column were obtained by dividing the LOD by 2.

REFERENCES

DTSC. 1990a. Technical Standards for Selecting Soil Sampling Designs for Hazardous Waste Sites. California Environmental Protection Agency, Department of Toxic Substances Control. Draft.

DTSC. 1990b. Standards for Estimating Parameters of Lognormally Distributed Populations. California Environmental Protection Agency, Department of Toxic Substances Control. Draft.

Gilbert, R.O. 1987. Statistical Methods for Environmental Pollution monitoring. Van Nostrand Reinhold Company, New York.

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Hartung, R. and Reed. L. 1987. Estimation of Average Concentration in the Presence of a Non-detectable Value. NIOSH, Dept. of Public Health, Cincinnati, Ohio. Draft report.

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OFFICE OF THE SCIENCE ADVISOR

GUIDANCE

CHAPTER 5

Selection, Use and Limitations of Indicator Chemicals for Evaluation of Exposure to Complex Waste Mixtures

ABSTRACT

Quantitative evaluation of all chemicals of potential concern is the most thorough approach for assessing potential health risks posed by exposures to chemicals emanating from hazardous waste sites and permitted facilities. Utilization of computer spreadsheet programs facilitates carrying all chemicals of potential concern through the risk assessment. It is expected most quantitative risk assessments of hazardous waste sites and permitted facilities will evaluate all chemicals of potential concern. However, for certain sites or facilities, the list of potentially site-related chemicals remaining after quantitation limits, qualifiers, blank contamination and background have been evaluated may exceed a manageable number. In other instances, there may be a number of individual chemicals for which toxicity data and/or health-based criteria are not available. In such cases, it is reasonable to use an indicator chemical approach to provide an estimate of the potential health risks associated with exposure to these substances.

Chemicals accounting for at least 95% of the risk are to be considered in the comprehensive risk assessment. As discussed in this document, chemicals should not be eliminated from evaluation if they possess certain types of toxicity or toxic potency, e.g., known human carcinogens. The indicator chemical should be similar in terms of environmental fate, transport, persistence, and inherent toxicity to the chemicals it is to represent, and should not be used for special environmental routes, such as the food pathway exposure route. Examples of how to determine chemical class, and how to select indicator chemicals, are provided in this document. It should be recognized that the indicator chemical approach requires a significant expenditure of time and effort to implement and to justify and may exceed the time needed to simply carry all chemicals of potential concern through a comprehensive quantitative risk assessment.

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Selection, Use and Limitations of Indicator Chemicals for Evaluation of Exposure to Complex Waste Mixtures

1 INTRODUCTION

1.1 Purpose

1.1.1 Necessity

Quantitative evaluation of all chemicals of potential concern is the most thorough approach for assessing potential health risks posed by exposures to chemicals emanating from hazardous waste sites and permitted facilities. Utilization of computer spreadsheet programs facilitates carrying all chemicals of potential concern through the risk assessment. It is expected most quantitative risk assessments of hazardous waste sites and permitted facilities will evaluate all chemicals of potential concern. However, for certain sites or facilities, the list of potentially site-related chemicals remaining after quantitation limits, qualifiers, blank contamination, and background have been evaluated may exceed a manageable number (i.e., greater than 25). In other instances there may be a number of individual chemicals for which toxicity data and/or health-based criteria are not available. In such cases it is reasonable to use an indicator chemical approach to provide an estimate of the potential health risks associated with exposure to these substances.

It is important to recognize that the time required to implement and justify the indicator chemical selection procedures detailed in this document may exceed the time needed to simply carry all the chemicals of potential concern through a comprehensive quantitative risk assessment. Therefore, it is anticipated that the procedures described in this document may be necessary only for the most complex hazardous waste sites and facilities or only for specific chemical waste mixtures.

1.1.2 Regulatory Context

The guidance provided in this document is intended to be consistent with the U. S. Environmental Protection Agency's (EPA's) Risk Assessment Guidance for Superfund, Volume I, Health Evaluation Manual (Part A), Interim Final (EPA/540/1-89/002, December 1989).

Currently, EPA requires that risk assessments of hazardous waste sites and permitted facilities follow the process and procedures described in the above referenced document.

1.2 Application

1.2.1 How and When Guidance Should be Used

This guidance is designed to provide information that will assist in the development of a quantitative human health risk assessment for a hazardous waste site or a permitted facility. The approach for selection of indicator chemicals for complex waste mixtures may or may not be adopted for a particular site or facility, depending on what is reasonable and appropriate for the facility and what is required by the Department of Toxic Substances Control (DTSC) toxicologists . Therefore, DTSC officials may decide to follow the guidance provided in this document, or to act at variance with the guidance, based on analysis of the individual, site-specific characteristics of the facility being evaluated. In general, since the indicator chemical approach requires a significant expenditure of time and effort to develop and justify, only complex sites or facilities that involve a substantial number of individual chemicals (i.e., greater than 25) will benefit from using this method. For this reason, the approach described herein should not be considered "simplified."

This document is intended to be used in conjunction with other guidance reports prepared by DTSC and the U. S. EPA, in particular the EPA's Risk Assessment Guidance for Superfund, Volume I, Human Health Evaluation Manual (Part A), (U. S. EPA 1989).

1.2.2 Who Should Use This Guidance

This guidance document is addressed primarily to individuals who conduct human health risk assessments for hazardous waste sites or facilities. It is also targeted to DTSC staff responsible for review and oversight of human health risk assessments. Officials at the federal, state, and local level who are involved in the remediation of hazardous waste sites and/or the permitting of facilities that handle hazardous wastes may also benefit from this guidance.

1.2.3 Major Points of the Guidance

This report provides specific guidance for reducing the number of individual chemicals that are included in a quantitative assessment of human health risk for exposure to chemicals originating from a hazardous waste site or permitted facility. The primary aspects of this guidance are:

- Known human carcinogens (i.e., classified by the U. S. EPA in weight-of-evidence Group A, or by International Agency for Research on Cancer (IARC) in Group I), known human developmental toxins, and known human reproductive toxins may not be eliminated from a quantitative human health risk assessment, even if the indicator chemical selection procedure indicates that such elimination is justified.

- Justification for selection of surrogate chemicals should include qualitative or quantitative consideration of environmental mobility, persistence, and bioaccumulation.

- In general, the indicator chemical procedure should not be employed to eliminate essential elements or toxic metals from consideration in a human health risk assessment.

- All chemicals detected at the site or facility being evaluated should be grouped into classes that reflect similarity of chemical structure.

- The toxicity of chemicals that either (a) lack a toxic potency value, or (b) are poorly identified or identified only by generic description (e.g., "unidentified glycol ethers"), is assumed to be equivalent to the toxicity of the most toxic member of the same chemical class.

- To identify a set of indicator chemicals, each chemical is ranked by calculating an arithmetic expression that accounts for toxicity, concentration in each medium of exposure, and the toxicity and concentration of all the chemicals detected at the facility. Each chemical class must be represented by at least one chemical (i.e., this procedure cannot be used to eliminate entire classes of chemicals). Carcinogens and noncarcinogens are evaluated in separate analyses. This procedure is intended to ensure that chemicals accounting for at least 95 percent of the risk associated with a facility are considered in the comprehensive risk assessment.

1.3 LIMITATIONS

It is important to recognize that the time required to implement and justify the indicator chemical selection procedures detailed in this guidance document may exceed the time needed to simply carry all of the chemicals of potential concern through a comprehensive quantitative risk assessment. Therefore, it is anticipated that the procedures described in this document may be applicable only for the most complex hazardous waste sites and facilities or only for specific chemical waste mixtures.

2 METHODS

2.1 CONSULTATION WITH THE DTSC

The purpose of a quantitative risk assessment of a hazardous waste site or permitted facility is to provide a reasonable upper bound estimate of the potential health risks associated with exposures to chemicals emanating from such facilities. The results of a quantitative risk assessment are used in part for, and indeed may be the basis for justification of, a risk management decision concerning remedial or control measures at the site or facility. Therefore, it is necessary that a risk assessment be accurate and thorough, and that all potential chemical exposures be evaluated. Since elimination of potential chemicals of concern from consideration in a risk assessment could lead to underestimation of the potential health threats posed by chemicals emitted from the site or facility, it is prudent and in the best interest of DTSC and the citizens of California for DTSC to review any and all proposals by interested parties to eliminate from consideration any chemicals of potential concern from a quantitative risk assessment. Written approval by a DTSC toxicologist or project manager must be obtained prior to DTSC sanction of the elimination of chemicals of potential concern from consideration in a risk assessment. The DTSC toxicologist's review and evaluation shall be in writing, and form a portion of the available public record, and shall include a scientifically supported expert opinion as to whether or not each such proposal is scientifically based, adequately justified, and likely to result in a significant underestimation of the potential health risks posed by the site or facility. In general, this review will be completed within six weeks from receipt of the proposal by the Toxicology and Risk Assessment Section.

2.2 DOCUMENTATION OF THE RATIONALE FOR ELIMINATING CHEMICALS OF CONCERN FROM CONSIDERATION IN THE RISK ASSESSMENT

Since the risk assessment report is a part of the public record, and contributes to DTSC's or the interested party's risk management decision, it is necessary that a list of all chemicals eliminated from consideration from a risk assessment and the rationale for eliminating these chemicals from the quantitative risk assessment, based upon the procedures detailed in this guidance document, be clearly stated in the main body of the risk assessment report.

2.3 HISTORICAL SITE-SPECIFIC USE INFORMATION

Historical data concerning chemicals, waste processes, etc., associated with site activities often provide important information concerning the types of, and possible sources for, contaminant releases into the environment. A quantitative risk assessment should be a comprehensive document that addresses the potential health threats associated with chemicals associated with both current and past hazardous waste generation, storage , and disposal procedures. However, it is acceptable to eliminate from consideration in the quantitative risk assessment chemicals historically associated with site or facility activities if the indicator chemical selection procedures outlined in this guidance document shows that such an elimination is justified.

2.4 KNOWN HUMAN CARCINOGENS

The classification of a chemical by EPA or by the IARC as a known human carcinogen means that these organizations have concluded that epidemiological scientific evidence clearly shows a causal association between exposure to these substances and the development of cancer in humans. Therefore, there is a clear human health threat when humans are exposed to these substances, and a quantitative risk assessment of a hazardous waste site or facility emitting such substances into the environment must address the potential human health threats posed by these substances.

DTSC recognizes that both inherent toxicity and exposure are necessary to produce a health risk, even for substances that are known human carcinogens. However, the likelihood that such substances would pose a cancer risk to exposed humans is greater than that for exposures to substances classified as probable or possible carcinogens, based upon experimental observations in laboratory animals. To ensure that the potential health risks posed by those substances most likely to adversely affect human health are not eliminated from evaluation in a quantitative risk assessment, to meet the concerns of the public regarding risks posed by known human carcinogens, and to provide the risk manager with sufficient human health risk information to make an informed decision, known human carcinogens (EPA Group A, IARC Group 1) should not be eliminated from evaluation in a quantitative risk assessment even if the indicator selection procedures indicate such an elimination is possible.

2.5 KNOWN HUMAN DEVELOPMENTAL AND REPRODUCTIVE TOXINS

The classification of a chemical known to be a human reproductive or developmental toxin is based upon epidemiological scientific evidence that clearly shows a causal association between exposure to these substances and the production of developmental or reproductive toxicities in humans. Therefore, there is a clear threat to human health when humans are exposed to these substances, and a quantitative risk assessment of a hazardous waste site or facility emitting such substances into the environment must address the potential human health threats posed by these substances.

DTSC recognizes that both inherent toxicity and exposure are necessary to produce a health risk, even for substances that are known human reproductive and developmental toxins. However, the likelihood that such substances would pose a health threat to exposed humans is greater than that for exposures to substances classified as reproductive or developmental toxins, based solely upon experimental observations in laboratory animals. To ensure that the potential health risks posed by those substances most likely to adversely affect human health are not eliminated from evaluation in a quantitative risk assessment, and to meet the concerns of the public regarding risks posed by known human reproductive and developmental toxins, and to provide the risk manager with sufficient human health risk information to make an informed decision, known human reproductive and developmental toxins should not be eliminated from evaluation in a quantitative risk assessment even if the indicator selection procedures indicate such an elimination is possible.

2.6 MOBILITY, PERSISTENCE, AND BIOACCUMULATION AND ECOLOGICAL EFFECTS

Exposure to chemicals contaminating a hazardous waste site or facility is governed by a complex interplay of chemical specific physio-chemical parameters and site-specific characteristics. The potential for human exposure to such hazardous chemicals is dependent, in part, upon the fate, transport, and/or persistence of these substances in environmental media, or bioconcentration in flora or fauna. The procedures detailed in this document for the selection of indicator chemicals do not explicitly include a component to assess environmental fate, transport, and persistence of hazardous waste chemicals. Therefore, it is necessary to apply scientific judgment, as well as the objective criteria detailed in this document, in the selection of indicator chemicals to ensure that substances that are highly mobile in the environment, substances that are highly persistent in the environment, and substances that are highly bioconcentrated are not eliminated from consideration in the risk assessment. The actual human health risks posed by such substances may not be fully appreciated during initial evaluations, yet, due to environmental transport, persistence or bioconcentration of such substances, humans may ultimately be exposed to these substances at a much larger level than would be estimated by simply evaluating concentration and toxicity data alone. The main body of the risk assessment report shall include a qualitative or quantitative evaluation of mobility, persistence and bioaccumulation in relation to the selection of indicator chemicals. For each indicator chemical chosen, written justification shall be provided to document that environmental fate, transport, persistence, bioaccumulation, ecological effects were evaluated in the selection process.

The intent of this recommendation is to ensure that consideration is given to substances that may migrate in the environment and to substances that are highly bioconcentrated since the actual human health risks posed by such contaminants may not be fully appreciated during initial site evaluations. For such substances, in particular, chemicals which are bioconcentrated in food stuffs, fish, shellfish, or livestock, humans could be exposed to a much larger extent than would be estimated based upon intakes of air, water, and soil. It is also of importance to consider environmental fate when evaluating soil and ground water contaminants, since it is possible that, at the time of investigation, significant concentrations may not be present in ground water, but could reasonably be expected to migrate into ground water prior to effective remediation of the contaminated soil.

2.7 SPECIAL EXPOSURE ROUTES

The indicator chemicals selected according to the procedures outlined in this guidance may not be applicable to assessing ecological threats or for assessing health threats from the food pathway or for assessing threats due to volatilization from contaminated household water into indoor air. Therefore, the indicator chemical procedure should not be used for special exposure routes (e.g., the food pathway exposure route, volatilization into indoor air from household water, etc.).

2.8 GROUPING CHEMICALS BY CLASS

Some examples of appropriate chemical classes (and members of these classes) that are commonly associated with hazardous waste sites and permitted facilities are included in Appendix A. Neither the chemical classes nor the members of each class are to be taken as comprehensive. Rather, this information is provided only for illustrative purposes. Selection of chemical classes should be consistent with the logic of this list, and, in addition, it may be beneficial to also consider environmental fate and transport considerations when grouping chemicals.

If a chemical is to be chosen as an indicator chemical to represent several chemicals, then the indicator chemical should be similar in terms of environmental fate, transport, persistence and inherent toxicity of the chemicals it is to represent. In many, but not all cases, chemicals with similar structures are likely to exhibit similar physio-chemical properties and similar toxicities. Therefore, the chemicals contaminating a particular medium are first grouped according to chemical class, so that an indicator chemical (or if necessary, several indicator chemicals) can be chosen to represent each and every class of chemical contaminants.

Separately, for each medium (air, water, soil), all of the chemicals detected at the site/facility should be grouped into classes based upon chemical structure, chemical class, or other chemical similarities.

Do not group solely by toxicity characteristics.

Do not group all carcinogenic or all noncarcinogenic chemicals without regard to chemical class, structure, or other chemical similarities.

Do not group chemicals by analytic techniques or physio-chemical properties (i.e., do not group chemicals into the classes of volatile organic compounds or semi-volatile organic compounds).

2.9 EVALUATION OF THE FREQUENCY OF DETECTION OF EACH CHEMICAL

Chemicals that are infrequently detected may be artifacts in the data due to sampling, analytical, or other problems, and therefore may not be related to site operations or disposal practices. Consider the chemical as a candidate for elimination from the quantitative risk assessment if it meets the criteria for a laboratory contaminant as specified in the EPA Risk Assessment Guidance for Superfund, Human Health Evaluation Manual, December 1989.

Available modeling results may indicate whether monitoring data that show infrequently detected chemicals are representative of only their sampling locations or of broader areas. Because chemical concentrations at a site are spatially variable, the risk assessor can use modeling results to project infrequently detected chemical concentrations over broader areas when determining whether the subject chemicals are relevant to the overall risk assessment. In general, when only limited characterization data is available (e.g., less than 20 samples per medium), it is inappropriate to eliminate infrequently detected chemicals. For the extensively characterized site or facility, any detection frequency limit to be used (e.g., five percent) as justification for elimination of infrequently detected chemicals should be approved by a DTSC toxicologist or site manager.

In addition to available monitoring data and modeling results, the risk assessor will need to consider other relevant factors (e.g., presence of sensitive subpopulations) in recommending appropriate site-specific limits on inclusion of infrequently detected chemicals in the quantitative risk assessment. For example, the risk assessor should consider whether the chemical is expected to be present based on historical data or any other relevant information (e.g., known degradation products of chemicals present at the site, modeling results). Chemicals expected to be present should not be eliminated based on their low frequency of detection.

For some chemicals the sample quantitation limits may exceed the concentration of concern for potential adverse health effects. Examples include benzene and vinyl chloride. In such cases it may be necessary to utilize more sensitive analytical techniques, or alternatively, assume that the chemicals of potential concern are present but at some level below the sample quantitation limit. For further guidance, refer to the DTSC guidance document on use of concentration data and to EPA Risk Assessment Guidance for Superfund, December 1989.

The reported or modeled concentrations and locations of chemicals should be evaluated to determine if the distribution "hotspot" should not be eliminated from the risk assessment. Always consider detection of particular chemicals in all sampled media because some media may be sources of contamination for other media. For example, a chemical that is infrequently detected in soil (a potential ground water contamination source) probably should not be eliminated as a site contaminant if the same chemical is frequently detected in ground water. In addition, infrequently detected chemicals with high concentrations should not be eliminated.

Therefore, for each chemical in each medium (air, water, soil) document frequency of detection data, and evaluate such data to determine if infrequently detected substances could be artifacts due to problems associated with sampling or analysis or other procedures.

2.10 EVALUATION OF ESSENTIAL ELEMENTS

Essential elements, defined as essential human nutrients and toxic only at very high doses (i.e., much higher than those that could be associated with contact at the site) should be candidates for elimination from a quantitative risk assessment of a hazardous waste site or permitted facility. Examples of such chemicals are iron, magnesium, calcium, potassium, sodium, and zinc. Essential elements that should not be eliminated from consideration include arsenic, selenium, copper, and chromium, since these metals pose a significantly greater risk to health and the environment.

Prior to eliminating essential elements from the risk assessment, they must be shown to be present at levels that are not likely to be associated with adverse health effects. The determination of acceptable dietary levels for these substances is often very difficult. Literature values concerning acceptable dietary levels may conflict and may change fairly often as new studies are conducted. For example, arsenic--a known human carcinogen--is considered by some scientists to be an essential nutrient based on animal experiments; however, acceptable dietary levels, if any, are not known for humans. Therefore, arsenic should be retained in the risk assessment. Another example is chromium. Chromium (III) is considered to be an essential nutrient, however, chromium (VI) is considered to pose a carcinogenic risk to humans.

For these reasons, the use of an indicator chemical approach for essential elements is not recommended.

In summary, the use of an indicator chemical approach for essential elements is generally not acceptable since the toxicity characteristics of each element are unique and it is therefore difficult, if not impossible, to quantitatively approximate the total potential risk of all essential elements by use of an indicator element.

2.11 EVALUATION OF TOXIC METALS

The indicator chemical approach for toxic metals is not recommended. Toxic metals include some essential elements, such as arsenic and chromium, as well as such nonessential elements as vanadium, beryllium, and barium. Such toxic metals should not be eliminated from consideration in the quantitative risk assessment unless the concentrations can be shown to be equivalent to naturally occurring levels. For guidance in determining background concentrations of toxic metals refer to EPA Risk Assessment Guidance for Superfund, Human Health Evaluation Manual, Chapter 5. Note that in some cases, background concentrations may present a significant risk, and while cleanup may or may not eliminate this risk, it may be necessary to evaluate background risk to provide important information to the affected public and to risk managers. If background concentrations of inorganic substances pose significant risks, then it is suggested that the quantitative risk assessment present risk estimates for the risks associated with exposure to the background concentration, the site concentration, and the total concentration.

2.12 SELECTION OF AN INDICATOR CHEMICAL FOR A CHEMICAL THAT IS INADEQUATELY IDENTIFIED OR THAT LACKS RELEVANT TOXICITY CRITERIA

For some chemicals a toxicity value may not be available from either Cal-EPA or EPA, and in some instances the analytical characterization of the chemical contaminants may be incomplete. In such cases, it is necessary to assume that the toxicity of these compounds were equivalent to the most toxic chemical within the chemical class for which the compound(s) of concern is a member. The toxicity value of the most toxic chemical within the class shall be used, for both the indicator selection procedure and for subsequent quantitative risk assessments, irrespective of the presence or absence of this most toxic chemical in the media of concern.

For example, for chemicals that are poorly identified (e.g., "unidentified glycol ethers") and for chemicals for which entirely health-based criteria are not available (e.g., 1-(2-methoxy-1-methylethoxy)-2)-1-methylethoxy)-2-propanol) it is necessary to consider these substances as if their toxicity were equivalent to the most toxic glycol ether, 2-methoxyethanol acetate. The toxicity value for 2-methoxyethanol acetate should be used initially for the indicator chemical selection procedure. If, using the indicator chemical selection procedure, the compounds(s) described as "unidentified glycol ethers" is selected as an indicator chemical for a subsequent risk assessment, then the toxicity value for 2-methoxyethanol acetate should be used in the quantitative risk assessment to calculate potential human health effects associated with exposure to the compound(s) described as "unidentified glycol ethers".

2.13 EVALUATION OF CHEMICALS OF POTENTIAL CONCERN USING A CONCENTRATION-TOXICITY SCREENING PROCEDURE

The aim of this screening procedure is to identify, using an objective, readily verifiable, arithmetic procedure, those chemicals in a particular medium that based on concentration and toxicity, are most likely to contribute significantly to potential human health threats as a result of exposure to the contaminated medium. Once this has been accomplished, indicator chemicals can be chosen such that it is highly probable that those chemicals eliminated from consideration in the quantitative risk assessment will not pose a significant risk.

The Individual Indicator Chemical Score (IICS), Total Indicator Chemical Score for Carcinogens (TICSC), Total Indicator Chemical Score for Noncarcinogens (TICSN), and associated ratios) parameters developed for the indicator chemical selection procedure are to be used solely for the potential reduction of the number of chemicals carried through a risk assessment of a hazardous waste site or facility. They have no meaning outside the context of this procedure, and they should not be considered as a quantitative measure to judge a chemical's toxicity or risk to humans, or as a substitute for a formal risk assessment.

2.13.1 Evaluation Procedure

Step 1: Identify the particular chemicals in each medium that--based upon concentration and toxicity--are likely to significantly contribute to the potential health risks associated with exposure to each medium. (An example is included in Appendix B)

For each class of chemicals in each medium, divide the chemicals detected into carcinogens and noncarcinogens. For the purposes of this evaluation carcinogens are defined as substances classified by EPA as "known human carcinogens", "probable human carcinogens", and "possible human carcinogens"; compounds classified by the IARC as "carcinogenic to humans", "probably carcinogenic to humans", and "possibly carcinogenic to humans", compounds classified by DTSC as carcinogens; compounds classified by DHS-Health Hazard Assessment Division as carcinogens; and compounds listed as carcinogens under Proposition 65 regulations.

This is necessary so that the indicator chemicals chosen reflect the potential of the chemical contaminants to cause both systemic toxicity and carcinogenicity. Two of the most important factors when determining the potential effect of excluding a chemical in the risk assessment are its measured concentrations at the site and its toxicity.

Calculate an Individual Indicator Chemical Score (IICS) for each chemical in each medium.

where:

Cij = Concentration of chemical i in medium j; the concentration units must be mg/vol. of medium for air and water, and mg/kg for soil.

Tij = Toxicity value for chemical i
(mg/kg/day)-1

The concentration of each chemical shall be the maximum detected concentration in each medium, irrespective of the sample depth (soil) or whether or not the aquifer is considered to be of current or future beneficial use (water). Concentration shall be expressed in units of mg/liter for water, mg/m3 for air, and mg/kg for soil.

Each chemical in a medium is then scored according to its concentration and toxicity to obtain an IICS. In obtaining the IICS, the concentration to be used is the maximum concentration of the chemical detected in the medium. This step simplifies the analysis, eliminates the need to consider bias sampling, and also ensures that chemicals of concern are not eliminated due solely to variability in their horizontal or vertical distribution in the medium.

To calculate Tij from a Reference Dose (RfD)

$$Tij = \frac{1}{RfD}$$

To calculate Tij from a Cancer Potency Slope (CPS).

$$Tij = CPS$$

The hierarchy for selection of the appropriate Tij to use when a given chemical has more than one health criteria shall be, in order of preference:

A. Cancer potency slope factors or reference doses promulgated into California regulations.

B. Cancer potency slope factors or reference doses used to develop environmental criteria promulgated into California regulations. Examples include cancer potency slope factors or reference doses used in deriving State drinking water Maximum Contaminant Levels (MCL) and cancer potency slope factors used in deriving "no significant risk levels" under the State's Safe Drinking Water and Toxic Enforcement Act of 1986 (Prop 65) . Note: The entirely health-based dose criteria should be used to estimate risk, and not the resulting risk management environmental concentration criteria (the CPS not the MCL).

C. Cancer potency slope factors or reference doses from the U. S. Environmental Protection Agency's Integrated Risk Information System (IRIS).

D. Cancer potency slope factors or reference doses from the U. S. Environmental Protection Agency's Health Effects Assessment Tables (HEAST, the most current edition).

The toxicity values to be used are entirely health-based criteria derived by Cal-EPA or the EPA (IRIS--Reference Doses or Cancer Potency Factors). Although other criteria from other regulatory programs may be available, they have limited application since they may not be entirely health-based criteria (e.g., State and Federal MCL for drinking water, OSHA Permissible Exposure Limits, ACGIH Threshold Limit Values).

Step 2: Calculate a Total Indicator Chemical Score for Carcinogens (TICSC) for each medium by summing all Individual Indicator Chemical Scores (IICS) for carcinogens.

Once IICSs have been calculated for each chemical in each medium, then the TICSC is calculated for each medium by summing all IICSs for carcinogens separately for each medium.

TICSC(water) = sum IICS(water) for carcinogens

TICSC(air) = sum IICS(air) for carcinogens

TICSC(soil) = sum IICS(soil) for carcinogens

Step 3: Calculate a Total Indicator Chemical Score for Noncarcinogens (TSCSN) for each medium by summing all Individual Indicator Chemical Scores (IICS) for noncarcinogens.

Once IICSs have been calculated for each chemical in each media, then the TICSN is calculated for each medium by summing all IICSs for noncarcinogens separately for each medium.

TICSN(water) = sum IICS(water) for noncarcinogens

TICSN(air) = sum IICS(air) for noncarcinogens

TICSN(soil) = sum IICS(soil) for noncarcinogens

Step 4: For each medium calculate the ratio of the Individual Indicator Chemical Score (IICS) for each carcinogen to the Total Indicator Chemical Score for Carcinogens (TICSC) for the respective medium.

Calculate the value of the IICS for each carcinogenic chemical in each medium divided by the respective media-specific TICSC. The IICS/TICSC ratio provides an approximation of the relative risk for each chemical in each medium.

Step 5: For each medium calculate the ratio of the Individual Indicator Chemical Score (IICS) for each noncarcinogen to the Total Indicator Chemical Score for Noncarcinogens (TICSN) for the respective medium.

Calculate the value of the IICS for each noncarcinogenic chemical in each medium divided by the respective media-specific TICSN. The IICS/TICSN ratio provides an approximation of the relative risk for each chemical in each medium.

Step 6: Select a Set of Indicator Chemicals to be Carried Through a Comprehensive Risk Assessment.

For most hazardous waste sites and permitted facilities it will be necessary to conduct a thorough quantitative risk assessment. If it is desired to use an indicator chemical approach for this comprehensive risk assessment, then indicator chemicals are selected for each medium by selecting a set of indicator carcinogenic and noncarcinogenic chemicals, to include at least one carcinogen and one noncarcinogen from each class, such that the sum of the ratios of the IICS to the TICSC or to the TICSN, as appropriate, for the substances selected is equal to or greater than 0.95. This procedure ensures that only those chemicals that are least likely to produce adverse human health effects are eliminated from consideration in the comprehensive risk assessment. The 0.95 value is designed to ensure that those chemicals responsible for approximately 95 percent of the risks associated with the site are carried through the comprehensive risk assessment. If the quantitative risk assessment reveals that the cancer risk is equal to or exceeds 1 x 10-4 or that the Hazard Index is equal to or exceeds 20, then it may be necessary to review the indicator chemical selection process and augment the set of indicator chemicals with chemicals originally eliminated from consideration.

For each medium select a set of indicator carcinogenic chemicals, to include at least one chemical from each class, such that the sum of the ratios of the IICS to the TICSC for the substances selected is equal to or greater than 0.95.

For each medium select a set of indicator noncarcinogenic chemicals, to include at least one chemical from each class, such that the sum of the ratios of the IICS to the TICSC for the substances selected is equal to or greater than 0.95.

To estimate receptor point exposure concentration for the comprehensive risk assessment, the source term concentration for each surrogate chemical in each medium shall be the 95 percent upper confidence limit of the arithmetic mean concentration, in accordance with EPA and State guidance.

Since the chemicals selected using the indicator chemical selection procedure are estimated to contribute most significantly to the potential health risks, it may not be necessary to adjust the source term concentrations for the indicators selected to account for the total mass of contaminants. In such cases, the source term concentration for each indicator chemical in each medium should be the 95 percent upper confidence limit of the arithmetic mean concentration of the surrogate chemical, in accordance with EPA guidance (Risk Assessment Guidance for Superfund, Human Health Evaluation manual and DTSC guidance (Guidance Document for Use of Concentration Data).

2.14 DOCUMENTATION OF INDICATOR CHEMICAL SELECTION PROCEDURE

If the indicator chemical approach is utilized, then thorough documentation of the procedure is required to be included in the main body of the risk assessment report. A separate chapter detailing the methodology, calculations, selection of indicators, and supporting justification is desirable.

Whenever possible data should be presented in tabular format. The data shall include a list of all chemicals; chemicals grouped by chemical class; frequency of detection of each chemical in each medium; maximum concentration of each chemical in each medium; the health-based criteria used for the toxicity value (Tij) and a reference as to its source; calculated Individual Indicator Chemical Scores, Total Indicator Chemical Scores, the ratio for each chemical in each medium of the Individual Indicator Chemical Score divided by the appropriate Total Indicator Chemical Score (the risk ratios); the indicator chemicals selected for each medium, their risk ratios, and the sum of their risk ratios.

The discussion of the indicator chemical selection procedure and the justification for selection indicator chemicals shall be in sufficient detail so as to allow for independent verification of the indicator chemical toxicity/concentration selection procedure, and presented in language that is, as far as is feasible, readily understandable to the layman public.

REFERENCES

DTSC. 1992. Department of Toxic Substances Control. Use of Concentration Data In Exposure Assessments. Draft.

IARC. 1987. International Agency for Research on Cancer (IARC) Monographs on the Evaluation of Carcinogenic Risks to Humans. Supplement 7. Overall Evaluations of Carcinogenicity: An updating of IARC Monographs Volumes 1 to 42.

U. S. EPA. Environmental Protection Agency Integrated Risk Information (IRIS). This is a computerized data base which contains toxicity information and toxicity criteria for numerous chemicals. Accessible through MEDLARS.

U. S. EPA. 1989. Risk Assessment Guidance for Superfund Volume 1 Human Health Evaluation Manual (PART A) Interim Final (EPA/540-1-89/002, 1989).

U. S. EPA. 1991. Health Effects Assessment Summary Tables (HEAST).

APPENDICES

Appendix A--Classes of Chemicals and Representative Members of Each Chemical Class

Halogenated C1, C2, and C3 Compounds

Chloroform
Chloromethane
Dichloromethane (Methylene chloride)
Trichlorofluoromethane (Freon 11)
1,1-Dichloroethane
1,2-Dichloroethane (Ethylene dichloride)
1,1,1-Trichloroethane (TCA)
1,1,2-Trichloroethane
Chloroethylene (Vinyl chloride)
1,1-Dichloroethylene (Vinylidene chloride)
cis-1,2,Dichloroethylene
trans-1,2-Dichloroethylene
Trichloroethylene (TCE)
Tetrachloroethylene (Perchloroethylene, PCE)
Carbon Tetrachloride

Ketones

2-Propanone (Acetone)
2-Butanone (Methyl ethyl ketone)
2-Hexanone (Methyl-n-butyl ketone, MNBK)
3,5,5-Trimethyl-2-cyclohexene-1-one (isophorone)

Chlorinated Phenols and Chlorinated Aromatics

Pentachlorophenol
2,4-Dichlorophenol
2,4,5-Trichlorophenol
2 -Chlorophenol
4-Chloro-3-Methylphenol
Chlorobenzene
1,4-Dichlorobenzene

Phthalate Esters and Related Compounds

Di(2-ethylhexyl)phthalate
Butylbenzylphthalate
Di-n-octylphthalate

bis(n-Butyl)phthalate
Di(2-ethylhexyl)phthalate (DEHP)
Di(2-ethylhexyl) adipate (DEHA)

Polychlorinated Dibenzo-p-dioxins and Dibenzofurans

Tetrachlorodibenzo-p-dioxins
Tetrachlorodibenzofurans
Pentachlorinated dibenzo-p-dioxins
Pentachlorinated dibenzofurans
Hexachlorinated dibenzo-p-dioxins
Hexachlorinated dibenzofurans
Heptachlorinated dibenzo-p-dioxins
Heptachlorinated dibenzofurans
Octachlorodibenzo-p-dioxin
Octachlorodibenzofurans

Organochlorine Pesticides

Hexachlorobenzene
4-4'-DDD
4-4'-DDE
4-4'-DDT
Dieldrin
Heptachlor
Heptachlor epoxide
Alpha-chlordane
Gamma-BCH (Lindane)
Gamma-chlordane
Endrin
Endrin Ketone
Toxaphene

Phenoxy Herbicides

2,4-D
2,4-DB
2,4,5-T
2,4,5-TP

Organophosphate Pesticides

Malathion
Parathion

Metals

Arsenic
Barium
Berylium
Cadmium
Chromium
Copper
Mercury
Nickel
Lead
Manganese
Selenium
Zinc
Vanadium

Acids

Hydrochloric acid
Sulfuric acid
Chromic acid
Nitric acid

Bases

Sodium hydroxide
Calcium hydroxide
Potassium hydroxide

Polychlorinated Biphenyls

Aroclor 1248
Aroclor 1260
Aroclor 1254
Aroclor 1242

Phenols

Phenol
2-4-dimethylphenol
4-methylphenol

Monocyclic Aromatic Compounds

Benzene
Ethylbenzene

Toluene
Xylenes (total)

Polycyclic Aromatic Hydrocarbons

2-Methylnaphthalene
Acenaphthene
Acenaphthalene
Anthracene
Benzo[a]anthracene
Benzo[b]fluoranthene
Benzo[ghi]prylene
Benzo[k]fluoranthene
Chyrsene
Dibenz[a,h]anthracene
Fluoranhene
Fluorene
Ideno[1,2,3]pyrene
Naphthalene
Phenanthrene
Pyrene

Glycol Ethers

2-methoxyethanol acetate
2-methoxymethanol
2-Butoxyethanol (Ethylene glycol monobutyl ether, Butyl CellosolveR)
2-2'Ethylmedioxybis(ethanol) (Triethylene glycol)
1-Ethoxy-2-(2-ethylethoxy)ethane (Diethylene glycol diethyl ether, Diethyl CarbitolR)
2-Phenoxyethanol
2-Phenoxethoxyethanol
1-(2-methoxy-1-methylethoxy)-2-propanol
1-(2-methoxypropoxy)-2-propanol
1-(2-(methoxy-1-methylethoxy)-2)-1-methlethoxy)-2-propanol

Alcohols

Methanol
Elthanol
2-Methyl-1-propanol
2-Ethyl-1-hexanol

Appendix B--Example for the Selection of Indicator Chemicals for One Medium

Chemicals Detected	Frequency of Detection	Maximum Concentration (ug/liter)
Chloromethane	6/50	1
Di(2ethylhexyl)phthalate (DEHP)	17/50	0.7
Methylene chloride	15/50	12
Naphthalene	8/50	1
Trichlorofluoromethane	6/50	3
1,1 Dichloroethane	38/50	222
Unidentified glycol ethers	30/50	7
Benzene	7/50	21
1,2 Dichloroethane	35/50	351
2,4 Dimethylphenol	6/50	45
1,1,1 Trichloroetane	26/50	420
Ethylbenzene	11/50	7
1,1,2 Trichloroethane	6/50	0.2
Toluene	13/50	1
Cis-Dichloroethylene	6/50	16
Phthalate esters (unidentified)	11/50	2.4
Trans-dichloroethylene	17/50	28
2-Methoxy ethanol	6/50	12
Xylenes	10/50	7
Pentachlorophenol	16/50	8
Trichloroethylene	27/50	7
Acetone	11/50	140
Carbon tetrachloride	8/50	3
2-Phenoxyethanol	17/50	10
Vinyl chloride	19/50	14
Methyl ethyl ketone	17/50	4
Tetrachloroethylene	37/50	89
Phenol	1/50	11
Benzo[a]pyrene	3/50	0.3
Fluorene	6/50	0.1
Propylene glycol monoethylether	2/50	1
2-Ethoxyethanol	17/50	10
Isopherone	6/50	3
Methylisobutyl ketone	9/50	9
Dimethyl phthalate	6/50	0.1
Diethyl phthalate	11/50	0.4
Butyl benzyl phthalate	7/50	0.1
2-Methoxyethanol acetate	3/50	3

Medium-Ground Water

Chemicals Detected	Frequency of Detection	Maximum Concentration (ug/liter)
Halogenated C1 and C2 Compounds		
Methylene chloride	15/50	12
Trichlorofluoromethane	6/50	3
1,2-Dichloroethane	35/50	351
1,1,1-Trichloroethane	26/50	420
1,1,2-Trichloroethane	6/50	0.2
Cis-dichloroethylene	6/50	16
Trans-dichloroethylene	17/50	28
Trichloroethylene	27/50	7
Carbon tetrachloride	8/50	3
Vinyl chloride	19/50	14
Tetrachloroethylene	37/50	89
Dibromochloropropane	7/50	1
Ketones		
Acetone	11/50	140
Methyl ethyl ketone	17/50	46
Isophorone	6/50	3
Methyl isobutyl ketone	9/50	9
Phthalates		
Di(2ethylhexyl)phthalate (DEHP)	17/50	0.7
Dimethyl phthalate	6/50	0.1
Diethyl phthalate	11/50	0.4
Butyl benzyl phthalate	7/50	0.1
Phthalate esters (unidentified)	31/50	2.4
Glycol Ethers		
2-Methoxyethanol	6/50	12
2-Ethoxyethanol acetate	13/50	30
2-Ethoxyethanol	17/50	10
2-Methoxyethanol acetate	3/50	3
Propylene glycol monomethyl ether	2/50	1
Unidentified glycol ethers	30/50	7
Monocyclic Aromatics		
Benzene	7/50	21
Ethylbenzene	11/50	7
Toluene	13/50	1

Xylenes	10/50	7
Phenols		
Pentachlorophenol	16/50	8
Phenol	1/50	11
2,4-Dimethylphenol	6/50	5
Polycyclic Aromatic Hydrocarbons		
Naphthalene	8/50	1
Fluorene	6/50	0.1
Benzo[a]pyrene	3/50	0.3

MEDIUM: WATER CHEMICAL CLASS: CARCINOGENS

Chemicals	**Concentration (mg/liter)**	**EPA Classification**	**Oral Cancer a/ Potency (mg/kg-day)-1**
Halogenated C1 and C2 Chemicals			
Dibromochloropropane	0.001	B2	7
Methylene chloride	0.012	B2	0.003
1,2-Dichloroethane	0.351	B2	0.07
1,1,2-Trichloroethane	0.0002	C	0.057 b/
Trichloroethylene	0.007	B2	0.015
Carbon tetrachloride	0.003	B2	0.15
Tetrachloroethylene	0.089	B2	0.051
Vinyl chloride	0.014	A	0.27
Phthalates			
Di(2-ethylhexyl) phthalate	0.0007	B2	0.0084
Unidentified phthalate esters	0.0024	B2c/	0.0084 c/
Monocyclic Aromatic Hydrocarbons			
Benzene	0.021	A	0.1
Phenols			
Pentachlorophenol	0.008	B2	0.018
Polycyclic Aromatic Hydrocarbons			
Benzo[a]pyrene	0.0003	B2	12

a/ Cal/EPA values unless otherwise noted.
b/ Value from EPA HEAST 1991.
c/ Since the identity of these substances is unknown, they are assigned EPA carcinogen classification and oral potency values equivalent to the most potent chemical within the phthalate ester chemical class.

MEDIUM: WATER | CHEMICAL CLASS: CARCINOGENS

Chemicals	IICSC	(IICSC/TICSC) x 100
Halogenated C1 and C2 Chemicals		
Dibromochloropropane	0.007	15.1
Methylene chloride	0.000042	0.0009
1,2-Dichloroethane	0.025	53.0
1,1,2-Trichloroethane	0.000011	0.025
Trichloroethylene	0.000105	0.23
Carbon tetrachloride	0.00045	0.97
Tetrachloroethylene	0.00454	9.80
Vinyl chloride	0.00378	8.16
Phthalates		
Di(2-ethylhexyl) phthalate	0.000006	0.013
Unidentified phthalate esters	0.000020	0.044
Monocyclic Aromatic Hydrocarbons		
Benzene	0.0021	4.53
Phenols		
Pentachlorophenol	0.000144	0.31
Polycyclic Aromatic Hydrocarbons		
Benzo[a]pyrene	0.0036	7.80

IICSC = Individual Indicator Chemical Score for Carcinogens
TICSC = Total Indicator Chemical Score for Carcinogens (TICSC) = 0.04634.

MEDIUM: WATER CHEMICAL CLASS : CARCINOGENS

CARCINOGENS SELECTED FOR THE QUANTITATIVE RISK ASSESSMENT

Chemicals	(IICSC/TICSC) x 100
Halogenated C1 and C2 Chemicals	
Dibromochloropropane	15.1
1,2 Dichloroethane	53.0
Tetrachloroethylene	9.80
Vinyl chloride	8.16
Phthalates	
Di(2-ethylhexyl) phthalate	0.013
Unidentified phthalate esters	0.044
Monocyclic Aromatic Hydrocarbons	
Benzene	4.53
Phenols	
Pentachlorophenol	0.31
Polycyclic Aromatic Hydrocarbons	
Benzo[a]pyrene	7.80
TOTAL	98.75

IICSC = Individual Indicator Chemical Score for Carcinogens.
TICSC = Total Indicator Chemical Score for Carcinogens.

MEDIUM: WATER CHEMICAL CLASS: NON-CARCINOGENS

Chemicals	Concentration (mg/liter)	Oral RfD a/	IICSNC	(IICSNC/ TICSNC) x 100
Halogenated C1 and C2 Chemicals				
Trichlorofluromethane	0.003	0.3	0.001	0.004
1,1,1-Trichloroethane	0.42	0.09	4.67	19.74
Cis-dichloroethylene	0.016	0.001	1.6	6.8
Trans-dichloroethylene	0.028	0.02	1.4	5.9
Ketones				
Acetone	0.14	0.1	1.4	5.9
Methyl ethyl ketone	0.046	0.05	0.92	3.9
Isophorone	0.003	0.2	0.15	0.063
Methyl isobutyl ketone	0.009	0.05	0.18	0.76
Phthalates				
Dimethyl phthalate	0.0001	1.0	0.0001	0.004
Diethyl phthalate	0.0004	0.8	0.0005	0.002
Butyl benzyl phthalate	0.0001	0.20	0.0005	0.002
Glycol Ethers				
2-Methoxyethanol	0.012	0.004	3.0	12.68
2-Ethoxyethanol acetate	0.03	0.3	0.1	0.42
2-Ethoxyethanol	0.01	0.4	0.025	0.11
2-Methoxyethanol acetate	0.003	0.002	1.5	6.3
Propylene glycol mono methyl ether	0.001	0.7	0.0014	0.006
Unidentified glycol ethers	0.007	0.002 b/	3.5	14.79

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a/ Values from EPA IRIS or EPA HEAST unless otherwise noted.
b/ Since the identity of these substances is unknown, they are assigned an EPA classification and oral reference dose equivalent to the most potent chemical within the glycol ether chemical class

IICSNC = Individual Indicator Chemical Score for NonCarcinogens
TICSNC = Total Indicator Chemical Score for NonCarcinogens (TICSNC) = 23.66

Monocyclic Aromatic Hydrocarbons				
Ethylbenzene	0.007	0.1	0.07	0.30
Toluene	0.001	0.2	0.005	0.02
Xylenes (mixed)	0.007	2.0	0.0035	0.015
Phenols				
Phenol	0.011	0.60	0.018	0.08
2,4 Dimethylphenol	0.005	0.001	5.0	21.13
Polycyclic Aromatic Hydrocarbons				
Naphthalene	0.001	0.004	0.25	1.1
Fluorene	0.0001	0.04	0.0025	0.011

MEDIUM: WATER CHEMICAL CLASS: NON-CARCINOGENS

NON-CARCINOGENS SELECTED FOR THE QUANTITATIVE RISK ASSESSMENT

Chemicals	**(IICSNC/TICSNC) x 100**
Halogenated C1 and C2 Chemicals	
1,1,1-Trichloroethane	19.74
Cis-dichloroethylene	6.8
Trans-dichloroethylene	5.9
Ketones	
Acetone	5.9
Methyl ethyl ketone	3.9
Phthalates	
Diethyl phthalate	0.002
Glycol Ethers	
2-Methoxyethanol	12.68
2-Methoxyethanol acetate	6.3
Unidentified glycol ethers	14.79
Monocyclic Aromatic Hydrocarbons	
Ethylbenzene	0.30
Phenols	
2,4-Dimethylphenol	21.13
Polycyclic Aromatic Hydrocarbons	
Naphthalene	1.1
TOTAL	98.5

MEDIUM: WATER CHEMICAL CLASS : ALL

CHEMICALS SELECTED FOR THE QUANTITATIVE RISK ASSESSMENT

Halogenated C1 & C2 Chemicals
Dibromochloropropane
1,2-Dichloroethane
Tetrachloroethylene
Vinyl chloride
1,1,1-Trichloroethane
Cis-dichloroethylene
Trans-dichloroethylene

Phthalates
Di(2-ethylhexyl)
phthalate
Unidentified phthalate
esters
Diethyl phthalate

Monocyclic Aromatic Hydrocarbons
Benzene
Ethylbenzene

Phenols
Pentachlorophenol
2,4-Dimethylphenol

Polycyclic Aromatic Hydrocarbons
Benzo[a]pyrene
Naphthalene

Ketones
Acetone
Methyl ethyl ketone

Glycol Ethers
2-Methoxyethanol
2-Methoxyethanol acetate
Unidentified glycol ethers

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OFFICE OF THE SCIENCE ADVISOR

GUIDANCE

CHAPTER 7

ASSESSMENT OF HEALTH RISKS FROM INORGANIC LEAD IN SOIL

ABSTRACT

This guidance describes a mathematical model for estimating blood lead concentration resulting from contact with lead-contaminated environmental media. A lead concentration of concern of ten micrograms per deciliter of whole blood is established. A distributional approach is used, allowing estimation of various percentiles of blood lead concentration associated with a given set of inputs. The method has been adapted to a computer spreadsheet.

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Assessment of Health Risks From Inorganic Lead in Soil

1 INTRODUCTION

1.1 Purpose

The purpose of this guidance is to provide a methodology for evaluating exposure and the potential for adverse health effects resulting from exposure to lead in the environment.

1.2 Application

Since most human health effects data are based on blood lead (Pb) concentration, this guidance presents a blood Pb concentration of concern for the protection of human health, and an alogrithm for estimating blood Pb concentrations in children and adults based on a multi-pathway analysis.

1.3 Limitations

It is anticipated that this guidance will be periodically revised to reflect the changing state of the science.

2 PRINCIPLES

2.1 Blood Lead Concentration Of Concern

The Pb concentration of concern in children and adults is ten micrograms (ug) per deciliter (dl) of whole blood. The point of departure for risk management is a 0.01 risk of exceeding this value.

2.2 Lead Exposure Pathways--Blood Lead Calculation

This method can be used to estimate blood lead concentrations resulting from exposure via the five pathways listed below. Each pathway is represented by an equation relating incremental blood lead increase to a concentration in a medium, using contact rates and empirically determined ratios. The contributions via the five pathways are added to arrive at an estimate of median blood lead concentration resulting from the multipathway exposure. Ninetieth, ninety-fifth, ninety-eighth, and ninety-ninth percentile concentrations are estimated from the median by assuming a log-normal distribution with a geometric standard deviation (GSD) of

1.42. The method has been adapted to a computer spreadsheet.

3 METHODS

Generalized equations describing uptake via the five exposure pathways are as follows:

Dietary Intake Equation

Pbb = dietary Pb * contact rate * dietary constant

where:

dietary Pb (ug Pb/kg diet) = (9.45 + 0.025 * mg Pb/kg soil) [1]
contact rate, adults = 2.2 kg diet/day [2]
contact rate, children = 1.3 kg diet/day [2]
dietary constant, children = 0.16 (ug Pb/dl blood)/(ug Pb/day) [3]
dietary constant, adults = 0.04 (ug Pb/dl blood)/(ug Pb/day) [4]

Drinking Water Intake Equation

Pbb = water Pb * contact rate * dietary constant

where:

drinking water Pb (ug Pb/l water) is a site-specific, measured value [5]
contact rate, adults = 1.4 l water/day [6]
contact rate, children = 0.4 l water/day [6]
dietary constant, children = 0.16 (ug Pb/dl blood)/(ug Pb/day) [3]
dietary constant, adults = 0.04 (ug Pb/dl blood)/(ug Pb/day) [4]

Soil and Dust Ingestion Intake Equation

Pbb = soil Pb * contact rate * soil constant

where:

soil Pb (ug/g) is a site-specific, measured value [15]
contact rate, children = 0.055 g/day [7]
contact rate, adults = 0.025 g/day [8]
soil constant, children = 0.07 (ug Pb/dl blood)/(ug ingested Pb/day) [9]
soil constant, adults = 0.018 (ug Pb/dl blood)/(ug ingested Pb/day) [9]

Inhalation Intake Equation

Pbb = atmospheric Pb * inhalation constant

where:

atmospheric Pb = local or regional ambient Pb (ug/m3) + (airborne dust * soil Pb)10
inhalation constant, children = 1.92 (ug/dl)/(ug/m3)11
inhalation constant, adults = 1.64 (ug/dl)/(ug/m3)11
airborne dust (g/m3) is a site-specific, measured value with a default value

of 0.00005.

Dermal Contact Intake Equation

Pbb = soil Pb * contact rate * soil constant
where:
soil Pb (ug Pb/gm soil) is a site-specific, measured value
contact rate, children = 1.4 gm soil/day [12]
contact rate, adults = 1.85 gm soil/day [13]
soil constant = 0.0001 (ug Pb/dl blood)/(ug dermal Pb/day) [14]

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1 Derived as follows: (0.945 * 10 ug/kg) + (0.055 * 0.00045 * soil Pb in mg/kg * 1000 ug/mg). Assumes that 5.5% of the diet consists of home-grown produce with the other 94.5% supplied by a homogeneous source with a lead content of 10 ug/kg. If food production on the site can be ruled out, use 10 ug/kg for dietary lead (EPA, 1989b, Bolger, et.al., 1990). Home-grown produce is assumed to contain 0.045% of the lead level in the soil.

2 Based on a report by Pennington (1983). For this method, a one-year-old child shall represent all children, based on the assumption that protecting the one-year-old child will protect all children.

3 Based on a study by Ryu, et.al. (1983)

4 Based on a report by FDA (1990)

5 Pb concentrations in local water supplies as consumed. If site-specific data are unavailable, a value of 15 ug/l may be used.

6 EPA (1989b)

7 Based on Calabrese (1990). Deliberate soil ingestion (soil pica) is represented as 0.00079 kg soil/day average.

8 For residential exposures and most occupational exposures, based on Calabrese (1990). Occupations with a high potential for soil ingestion (such as construction) should be represented as 0.00005 kg soil/day average.

9 These values are 44% of that for lead ingested with food or water, based on a study in rats which compared the bioavailability of lead acetate mixed with the diet to that of soil-bound lead (Chaney et.al., 1990).

10 The ambient air Pb concentration data are available from the California Air Resources Board, Technical Support Division. Data for the most recent year for the nearest monitoring station should be used. If monitoring data collected within the same air basin are unavailable, a value of 0.18 ug/m3 may be used, or consult with the DTSC project manager. Respirable airborne dust is assumed to be 0.00005 g/m3 unless site-specific data are available.

11 Based on EPA (1986)

12 Based on a soil adherence of 5 g/m2 and 0.28 m2 of exposed skin (EPA, 1989b).

13 Based on a soil adherence of 5 g/m2 and 0.37 m2 of exposed skin (EPA, 1989b).

14 This value is derived by multiplying the Pb ingestion:blood concentration ratio for adults (0.018 ug/dl per ug/day) by the ratio of dermal absorption [0.06% (Moore, et. al., 1980)] to oral absorption [11% (ATSDR, 1990)].

15 Developed according to Chapter 2 of this Guidance.

4 COMMENTS

4.1 Blood Lead Concentration Of Concern

The traditional reference dose approach to toxic chemicals is not applied to Pb because most human health effects data are based on blood Pb concentrations rather than external dose. Blood Pb concentration is an integrated measure of internal dose, reflecting total exposure from site-related and background sources. A clear no-observed-effect concentration has not been established for such Pb-related endpoints as birth weight, gestation period, heme synthesis and neurobehavioral development in children and fetuses, and blood pressure in middle-aged men. Dose-response curves for these endpoints appear to extend down to 10 ug Pb/dl or less (ATSDR, 1990).

4.2 Estimating Blood Lead Concentrations From Environmental Concentrations

Total Pb is generally used as the measure of Pb in various media, even though the disposition of Pb may differ according to its form. Insufficient data are available to justify differential treatment of different forms of inorganic Pb. However, if the lead at a particular site has been shown, in studies acceptable to DTSC, to be less bioavailable than the assumed values, lower bioavailability factors may be substituted for the default factors. Organic Pb is more readily absorbed through the skin and other membranes than inorganic Pb, and it must therefore be treated separately. Since it is less stable in the environment, it is usually a minor source of exposure.

In the absence of specific information about the population of interest, background exposures are estimated using norms developed from survey data.

4.3 Derivation Of Model Parameters

Unless the potential for on-site gardening can be ruled out, it is assumed that 5.5% of the diet consists of home-grown produce, based on EPA guidance (USEPA, 1991). Pb concentration in home-grown produce is calculated as 0.045% of that in the soil, based on plant uptake studies (Chaney, et.al., 1982). Background dietary Pb concentration (10 ug/kg) is based on a 1990 report based on FDA data (Bolger, et.al., 1990). The default drinking water Pb concentration is based on the federal action concentration of 15 ug/l at the tap (USEPA, 1991b).

The distribution of blood Pb concentrations for a given set of environmental inputs is a critical factor in protecting sensitive members of the population.

Based on a review of data from NHANES II and from several published studies of blood Pb concentrations in children living near point sources of lead, EPA concluded that blood Pb was generally log-normally distributed, that the geometric standard deviation (GSD) for children was between 1.3 and 1.53, and that 1.42 was a representative value for the GSD (USEPA, 1989c). Adult GSDs ranged from 1.34 to 1.40, which we do not consider to be sufficiently different from the range for children to justify using a different value for adults. The model assumes a log-normal distribution with a GSD of 1.42 and uses this information to estimate the fiftieth, ninetieth, ninety-fifth, ninety-eighth, and ninety-ninth percentile blood Pb concentration for a set of inputs. Since this distribution reflects the physiologic and behavioral variables including soil consumption, using upper bound values for contact rates would distort the percentiles corresponding to blood Pb concentrations.

The availability of Pb ingested with soil is based on a study which compared the absorption of soil Pb and Pb acetate incorporated into the diet of rats (Chaney, et.al., 1990). While the authors found a direct relationship between the Pb concentration in the soil and Pb bioavailability, the data did not define the shape of the concentration/ bioavailability curve sufficiently to allow extrapolation beyond the range studied. The highest observed bioavailability for soil lead concentrations less than 1000 ppm was 44% of that observed for Pb acetate, and this guideline adopts this value as a conservative estimate of bioavailability. To accurately assess the matrix effect, a variety of variables, including lead species, particle size, and soil type would have to be systematically examined at various Pb concentrations in soil.

The daily soil adherence to skin of 5 g/m2 (0.5 mg/cm2) is based on Driver et.al (1989). The dermal absorption factor of 0.0001 ug Pb/dl blood per ug dermal Pb/day was developed by multiplying the Pb ingestion:blood concentration ratio for adults (0.018 ug/dl per ug/day) by the ratio of dermal absorption [0.06% (Moore, et. al., 1980)] to oral absorption [(11% (ATSDR, 1990)]. Based on data in the Exposure Factors Handbook (USEPA, 1989b), the median skin area of arms, hands, feet, and legs of 1-year-old boys is estimated to be 0.28 m2, and the median skin area of arms and hands of men is estimated to be 0.37 m2.

The ratio of 0.16 ug/dl per ug/day ingested by children is a value derived from studies in infants by Ryu et.al. (1983). The ratio of 0.04 ug/dl per ug/day ingested by adults is an empirically-determined value recommended by EPA (1986) and FDA (1990). The default value for inadvertent soil/dust ingestion by children , 55 mg/day, is based on tracer studies reviewed by Calabrese, et.al. (1991). Adult soil consumption is 25 mg/day, based on EPA (1991a). DTSC uses soil consumption rates of 200 and 100 mg/day in calculating a reasonable maximum exposure for children and adults, respectively. However, reasonable maximum inputs are not recommended for use with the lead model because the model already considers the distribution of blood lead, which reflects variation in soil ingestion along with other variables. Soil consumption representing pica is 0.79 g/day, based on estimates by Calabrese et.al. (1991).

The slopes of 1.92 and 1.64 ug/dl of blood per ug/m3 of continuously-breathed air at atmospheric Pb concentrations <5 ug/m3 are based on results of experimental exposures and epidemiological studies which adjusted for airborne lead contributions to pathways other than inhalation. These studies found slopes ranging from 1.52 to 2.46 ug/dl per ug/m3 in children and 1.25 to 2.14 in adults (USEPA, 1986). The default airborne lead concentration is the highest monthly mean 24-hour value recorded in California in 1990.

4.4 Using This Guidance

This guidance may be implemented using a computer spreadsheet, which may be obtained from DTSC. The spreadsheet is based on DTSC Guidance, Volume 4, Chapter 1, which should be consulted for more general aspects of spreadsheet application. For this spreadsheet, soil concentration in mg/kg (ppm w/w) is entered in cell E7. The spreadsheet uses it in each calculation that is affected by soil Pb. Atmospheric Pb is entered in cell E6. Drinking-water Pb is entered in cell E8. If omission of the site-grown produce pathway can be justified, a "0" is entered in cell E9. Airborne dust level is entered in cell E10. The remainder of the cells are protected and should not be altered without approval of DTSC. Any such changes will require sufficient justification and must be documented.

4.5 Other Standards And Guidance

USEPA (1991c) considers lead to be a class B-2 carcinogen, with sufficient evidence in animals and inadequate evidence in humans. A carcinogenic potency has not been assigned. The federal MCL is 15 ug/l maximum at the tap with a maximum of 5 ug/l as a system-wide average (USEPA, 1991b). The Centers for Disease Control has stated that prevention activities should be directed at reducing children's blood Pb concentrations at least to below 10 ug/dl (CDC, 1991). The EPA has set 1.5 ug/m3 as the Pb concentration limit for ambient air (quarterly average) (USEPA, 1978). California's standard is also 1.5 ug/m3, but is based on a monthly average. The threshold limit value is 50 ug/m3 for workplace air (ACGIH, 1989).

FDA (1990) considers the Lowest Observable Adverse Effect Level (LOAEL) to be 10 ug/dl in children and fetuses, and 30 ug/dl in adults. They use empirically-derived ratios of 0.16 and 0.04 ug/dl per ug/day ingested to predict concentrations in young children and adults, respectively. Applying an uncertainty factor of ten results in provisional tolerable intake levels of 6 ug/day for children six or less, 15 ug/day for children over six, 25 ug/day for pregnant women, and 75 ug/day for men.

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OFFICE OF THE SCIENCE ADVISOR

GUIDANCE

CHAPTER 8

DDT IN SOIL: GUIDANCE FOR THE ASSESSMENT OF HEALTH RISK TO HUMANS

ABSTRACT

This Guidance Document was developed to addresses the risk to human health posed by the insecticide DDT in soil. The term "DDT" used herein describes p,p'-DDT, also known as 4,4-DDT, with the American Chemical Society name of 1,1,1-trichloro-2,2-bis(p-chlorophenyl)ethane. Within this document, the term " DDT_{tot}" refers to DDT and it's decomposition products DDD and DDE. All three agents are ubiquitous in California soil, due to the legal application of DDT for agricultural purposes prior to cancellation of the usage of DDT two decades ago. DDT_{tot} is a known animal carcinogen, which prompts the concern for human health.

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ACRONYMS

AAL	Applied Action Level
ATSDR	Agency for Toxic Substances and Disease Registry
CAS	Chemical Abstract Service
CDFA	California Department of Food and Agriculture
DDD	Isomers of dichlorodiphenyldichloroethane (trivial name); in older literature, often referred to as "TDE" *
DDE	Isomers of dichlorodiphenyldichloroethene (trivial name) *
DDT	Isomers of dichlorodiphenyltrichloroethane (trivial name)*
DDT_{tot}	Sum of isomers of DDT, DDD, and DDE
DHS	California Department of Health Servi ces
DTSC	California Department of Toxic Substances Control
FDA	United States Food and Drug Administration
IARC	International Agency for the Research of Cancer
IRIS	Integrated Risk Information System available by computer on-line from
OSWER	Office of Solid Waste Emergency Response (USEPA)
RAGS	Risk Assessment Guidance for Superfund manual from USEPA
TRAS	Toxicology and Risk Assessment Section
TSB	Technical Services Branch
TTLC	Total Threshold Limit Concentration
USEPA	United States Environmental Prot ection Agency

* See Appendix 18 for Chemical Abstract Service nomenclature.

DDT IN SOIL: GUIDANCE FOR THE ASSESSMENT OF HEALTH RISK TO HUMANS

1 INTRODUCTION

1.1 PURPOSE

This Guidance Document of the Department of Toxic Substances Control (DTSC) was developed to provide a risk assessment approach to DTSC personnel, as well as the general public, for use in: 1) quantitating adverse health risks to humans from exposure to soil contaminated with DDT, DDD, and/or DDE, and 2) calculating soil remediation levels which are health protective, on a site-specific basis. Specifically targeted is agricultural land being developed for new uses, assuming that DDT is present due to previous legal application on crops and not to illegal or inappropriate disposal practices. Soil is assumed to be the exclusive medium of exposure, unless other pathways are identified.

If other pathways are identified, a comprehensive risk assessment may be necessary.

1.2 OVERVIEW OF THE PROBLEM

DDT and it's metabolites, DDD and DDE, are ubiquitous contaminants in California farm land due to legal use of DDT, in the past, on crops for pest control. Pressure for development has placed much agricultural land into consideration for new uses. Concern for health risks to humans from exposure to DDT in developed farm land has posed whether remediation of DDT in soil is necessary.

DTSC, as a regulatory entity, is permitted to become involved only when DDT contamination is due to illegal or improper disposal. The California Department of Pesticide Regulation regulates current pesticide application only. Presently, no State agency has clear authority to regulate the remediation of soil containing DDT which got there from legal application to crops. Total Threshold Limit Concentrations (TTLCs) are often misused to fill this void. TTLCs are intended to provide a legal basis in deciding whether waste is hazardous in order to determine disposal procedures. The TTLC for DDT is not health-based and is therefore inappropriate for use as a generic remediation goal for DDT in soil. This Guidance Document provides guidance for site-specific risk determination, as well as calculation of remediation values appropriate for each individual situation.

To this end, a number of receptor- and case-specific exposure scenarios were constructed according to "real world" lifestyle and exposure estimates. "Typical" and "High" exposures were developed. The scenarios include the following:

1. Lifetime exposure in a residential setting (default, Appendices 1 and 2).

2. Residential exposure for 30 years for adults who work away from the home (Appendices 3 and 4).

3. Residential exposure for 30 years for adults who are homemakers, employed at home, or otherwise are at home for the full day (Appendices 5, 6, and 7).

4. Residential exposure for children of ages 1 through 17 (Appendices 8 through 11).

5. Recreational exposure in a community park for children of ages 1 through 17 years (Appendices 12 and 13).

6. Exposure at school for children of ages 6 through 17 (Appendices 14 and 15).

7. Inhalation of wind-borne dust/soil in a residential setting (Appendix 16).

8. Exposure by consumption of home-grown produce (Appendix 17).

In addition, three examples for calculation of soil remediation levels were developed. The first example was calculated with the default exposure values for adults living at home for 70 years. Example number two was developed using life-style specific exposure estimates for adults who live and work at the residence for 30 years. The third example concerns children living at home from birth to age 18.

Finally, the risk from consuming home-grown produce containing translocated DDT from soil is compared with the risk from consuming organochlorine pesticides present in the "average" American diet.

1.3 LIMITATIONS

- This document is not intended to be a general guide for risk assessment. It was written as guidance on how to develop case-specific exposure scenarios for the estimation of risk. Readers are referred to USEPA's Risk Assessment Guidelines for Superfund (USEPA, 1989a) for guidance on risk assessment parameters and procedures.

- Many of the assumptions used in the Appendices are based on personal or collective judgement and have no literature reference. Examples include the amount of time that teenagers spend at home on weekends, the amount of time that children are awake per day, and the surface area of exposed skin in children playing in a community park or attending school during warm or cool weather.

- In order to be health-protective, the risk assessment process uses numerous conservative assumptions to compensate for uncertainties in extrapolating from the results of animal tests to human exposure, and in estimating exposure where actual measurements are not available or possible. As such, the levels of risk calculated for the exposure scenarios in this document are likely to overestimate actual risk.

- This document is subject to change in accordance with new information. Therefore, readers should confer with DTSC regarding revisions to the document and which versions of the document are obsolete.

2 DEFINITIONS

Chemical Abstract Service (CAS) nomenclature are used to identify DDT as well as the metabolites/environmental degradation products, DDD and DDE, which are found in soil.

CAS nomenclature is given in Appendix 17 for the isomeric forms of DDT, DDD, and DDE which are likely to be found. The p,p'- isomers are most commonly found, although o,p'- isomers are occasionally detected. The m,p'- isomers are generally not found, as they were minor byproducts of the manufacturing process for DDT. The commercial process for synthesis of technical grade DDT involved condensation of chloral hydrate with chlorobenzene in the presence of sulfuric acid (IARC, 1979). According to IARC, the DDT isomers in technical DDT consisted of 65 to 80 percent of the p,p'-, 15 percent to 21 percent of the o,p'-, up to 1 percent m,p'-, and traces of o,o'- isomer. In addition, p,p'-DDD and dicofol could be present in concentrations up to 4 percent or 1.5 percent, respectively.

The term "DDT_{tot}" in this document, will be used generically to describe all isomers of DDT, DDD and DDE. Otherwise, the specific acronyms DDT, DDD, or DDE will refer to the p,p'-isomer of each entity only.

In order to avoid redundancy, the specific acronyms DDT, DDD, or DDE will refer to the p,p'-isomer of each chemical entity. DDT_{tot} will be used to refer to any of these three chemicals. Note that " DDT_{tot}" is equivalent to the term " DDTr" which frequently is used in other publications.

3 SOURCES OF CONTAMINATION

This document was developed to provide guidance concerning DDT_{tot} in soil which is present solely from previous legal agricultural activities. However, the exposure scenarios presented in the Appendices may be useful towards directing other pesticide remediation efforts regardless of contaminant source.

DDT_{tot} is ubiquitous in California soil due to heavy agricultural usage prior to cancellation in 1972. The extent of soil contamination has been documented by the California Department of Food and Agriculture (CDFA, 1985), as well as in numerous remedial investigation reports reviewed by this office. Therefore, agricultural land which is currently developed or being considered for new uses, such as residential tracts or parks, frequently contains DDT_{tot}.

Oftentimes, the levels of soil contamination with DDT_{tot} are greater than 1 ppm (1mg/kg), which exceeds the "Total Threshold Limit Concentration" (TTLC) for DDT_{tot}. TTLC's (Title 22, CCR, 66700) are promulgated values which are used for hazardous waste classification, i.e., to determine whether waste material is hazardous waste and must be taken to a hazardous waste facility, or can be disposed of otherwise. Therefore, the TTLC of 1 ppm for DDT_{tot} would determine whether disposal of excavated soil containing DDT_{tot} must involve a hazardous waste facility. However, the TTLC for DDT_{tot} is often misused as a "clean-up number" for remediation of agricultural land containing DDT_{tot} due to prior use on crops.

At the present time, DTSC lacks the authority to regulate DDT_{tot} which is in the soil due to previous legal application procedures on crops. Soil such as this containing DDT_{tot} is considered a hazardous waste only if removed from the site. DDT_{tot} in soil due to spillage or improper disposal activities, in contrast, may be regulated by existing DTSC procedures. Therefore, remedial action and/or border zone determinations may be applicable to portions of agricultural land containing localized areas of contamination due to spillage or improper pesticide disposal.

The purpose of this document is to provide guidance for the health-based appraisal of risk associated with exposure to DDT_{tot} in soil. This is to avoid the misuse of the TTLC, which is not health-based, for the determination of whether remediation is necessary.

4 SITE CHARACTERIZATION

The sampling protocol for a property must be appropriate for use in a quantitative risk assessment, or the data will be of little value.

A health risk appraisal can be no better than the data collection effort. To quote USEPA's Risk Assessment Guidance for Superfund (USEPA, 1989a): "The sampling strategies for a site must be appropriate for use in a quantitative risk assessment; if inappropriate, even the strictest QA/QC procedures...will not ensure the usability of the sample results."

The sampling protocol should be directed at defining plausible human exposure, as well as the extent of contamination. Both requirements are case-specific. For example, sampling of surface soil only would provide assessment of actual exposure in cases where the soil was intended to remain undisturbed, except for minor landscaping. Where construction or landscaping needs require excavation of subsurface soil to the surface, sampling of subsurface soil is necessary to evaluate human exposure. While complete delineation of the extent of both horizontal and vertical contamination is desirable, it may be required by local agencies.

Good sampling strategies, based on site characterization, also may justify exclusion of areas whose geography or vegetation preclude human access or contact.

The reader is referred to Volumes 1 and 3 of the DTSC "Guidance for Site Characterization and Multimedia Risk Assessment for Hazardous Substances Release Sites".

DDT_{tot} is a ubiquitous contaminant in California soil. Therefore, "background" soil data obtained from nearby areas are regarded to be of little value in the risk appraisal process for DDT_{tot} in soil. DDT_{tot} is a synthetic compound, so there is no natural "background" concentration in soil as there is for entities such as arsenic or asbestos. However, DDT is ubiquitous in the California environment due to widespread application prior to cancellation of use in 1972. The extent of contamination was reported by California Department of Food and Agriculture (CDFA, 1985). To quote: "CDFA collected 99 soil samples in 32 California counties from locations where DDT had been used in the past. All samples contained DDTr...Based on analysis of historical and empirical evidence, CDFA concluded that residues from legal applications of DDT, before its use was banned, appear to be the source of this contamination."

Because of widespread contamination, "background" samples taken offsite will likely contain DDT_{tot}. The soil levels could be equivalent to or greater than those found on site, confounding interpretation.

An alternative method is suggested : that "background" (off-site) exposure to DDT_{tot} be considered to be that amount present in the average American diet. Such information is available from the U.S. Food and Drug Administration (FDA). FDA extensively monitors pesticide levels in raw agricultural commodities as well as in prepared foods. Studies on prepared foods are often referred to as "Total Diet Studies" or "Market Basket Studies." In general, 234 individual food types are purchased four times a year in various cities. The foods are prepared as if to be eaten (peeled, cooked, etc.) and analyzed for over 200 pesticides. These results are used in conjunction with consumption information to calculate the average daily intake for each pesticide detected. Analysis of prepared food allows estimation of pesticide consumption in foods in the final form in which they are usually eaten, such as bread and apple pie. Results of a recent Total Diet Study can be found in Appendix C of the FDA pamphlet describing the program and available from FDA (FDA, 1989).

5 HAZARD IDENTIFICATION

DDT_{tot} is considered to be a "probable human carcinogen" by the U.S. Environmental Protection Agency (USEPA) and the Office of Environmental Health Hazard Assessment of the California Environmental Protection Agency.

Numerous studies have shown that DDT, DDD, and DDE are carcinogens in laboratory animals. These studies have received extensive review elsewhere and will not be described in this document (USEPA, 1984; ATSDR, 1989, IRIS, 1991). Based on the animal data, scientists at USEPA classified DDT, DDD, and DDE as "B2" carcinogens, that is, probable human carcinogens. The Toxicology and Risk Assessment Section (TRAS) agrees with that classification. USEPA also considers these agents to act as carcinogens by a non-threshold mechanism. TRAS leaves open the possibility that DDT_{tot} may be carcinogenic through a non- genotoxic, threshold mechanism. In the meantime, the examples provided in this document assume a mechanism having no threshold.

To date, available data in humans have shown no correlation between DDT_{tot} exposure and human cancer. The most recent study was that of Austin et al. (1989). In that study, DDT and DDE serum levels were quantitated in over 900 subjects who received a ten year prospective follow up for mortality. To quote: "There was no relation between either overall mortality or cancer mortality and increasing serum DDT levels." Previous reports also have shown no association between human cancer and exposure to DDT_{tot} (See Higginson, 1985).

However, the weight of evidence from animal studies advises that caution is prudent before discounting carcinogenic activity of DDT_{tot} in humans. Therefore, TRAS, in accord with USEPA, regards DDT_{tot} to be a "probable" human carcinogen in the absence of definitive epidemiological evidence to show otherwise.

6 DOSE RESPONSE

Cancer potency slope factors derived by the U.S. Environmental Protection Agency (USEPA) for DDT, DDD, or DDE, will be used for risk characterization. Slope factors given in the USEPA Integrated Risk Information System or Health Effects Assessment Summary Tables (IRIS and HEAST, respectively) will be used for dose-response estimates. The current slope factors are 0.34 kg-day/mg for DDT and DDE, and 0.24 kg-day/mg for DDD (IRIS, 1991). For the sake of simplicity, 0.34 kg-day/mg may be used for DDT_{tot} as a default value. Alternatively, the risk assessor may wish to use separate slope factors for DDT/DDE or DDD.

7 EXPOSURE

For the purpose of this Guidance, exposure to DDT_{tot} in soil is assumed to occur exclusively by ingestion of soil and the contact of soil with exposed skin. Examples were developed according to a residential scenario representing high-density housing, a community park and a school.

7.1 Residential Exposure Default Values

The default values for exposure frequency, duration, and body weight will be daily for 24 hours per day, 30 or 70 years, per a 70 year lifetime, and 70 kg for adults (USEPA, 1989a), respectively, for a residential scenario. However, TRAS encourages the development of other values and exposure scenarios on a case-specific basis, such as partial daily exposure for adults who work away from the residence on a daily basis, children/adolescents who attend school on a daily basis and leave "home" after graduation from secondary school, workplaces, or community parks, where exposure is periodic rather than continuous, less than lifetime, and could involve individuals weighing less than 70 kg. Examples of alternative, case-specific, scenarios are provided in the Appendices.

7.2 Soil Ingestion Rates

Default values for soil ingestion are 100 mg/day for adults, and 200 mg/day for individuals 6 years of age and less, according to guidance provided by USEPA (USEPA, 1989a, Page 4-40).

Note, however, that there are no universally agreed-upon rates for daily soil ingestion. Sedman (1989) performed an extensive review of the literature, which was available for children only. Using several data sources, a number of estimates for soil ingestion were derived for different age groups. Average age-specific values ranged from 590 mg/day for ages 1-2 to 110 mg/day for ages 17-18. Adults (ages 18-70) were assumed to be constant at 100 mg/day. A soil ingestion value of 150 mg/day was recommended for estimation of exposure for a 70 year lifetime. A description of how these values were derived via an exponential function curve fitting program is beyond the scope of this document.

Following Sedman's evaluation, Calabrese et al. (1989) published an elegant study using a mass balance approach to follow the fate of eight tracer elements in children. The tracers were normal constituents of soil. Fecal excretion of tracers was quantitated under control conditions, as was tracer ingestion via the diet. The mass balance difference was regarded to represent tracer intake via ingestion of soil. Ingestion of house dust was also considered, because the investigators found that tracer concentrations in house dust were comparable to those in outdoor soil. Results were reported in terms of soil ingestion, dust ingestion, and both values combined.

Median values for three of the tracers (aluminum, silicon, and yttrium) were regarded by the authors to be the most reliable, and gave soil ingestion rates of 29, 40, or 9 mg/day, respectively. Mean values were approximately four times greater, being 153, 154, or 85 mg/day for aluminum, silicon, or yttrium, respectively. The respective ninety-fifth percentile values were 223, 276, or 106 mg/day. The investigators regarded that there were no differences in values calculated from soil ingestion alone, or with inclusion of ingestion of house dust. Median values are comparable by either method, but the ninety-fifth percentile values are about two-fold greater when dust ingestion was included, being 478, 653, or 159 mg/day, respectively. TRAS concludes that values for dust and soil combined are more appropriate than for soil alone.

USEPA (1989a) recommended daily soil ingestion rates of 200 mg/day for children of ages one though six, and 100 mg/day for all older individuals. Based on Sedman's recommendations (1989) and the results of Calabrese et al. (1989), TRAS concurs with USEPA's recommendations. This represents a difficult problem, but TRAS feels that these values are health-protective when used with a typical residential scenario. Children with pica, or adults in occupational scenarios with individuals handling soil daily, would require separate estimates. In any event, TRAS will consider alternative values if based on laboratory data from animals, experimental data from human studies, and/or reasonable assumptions.

As examples, a number of plausible site- and receptor-specific scenarios were developed for Guidance. These are presented in the Appendices. The first scenario uses default values of 100 mg soil/day for 70 years (Appendix 1). The second scenario concerns adults who work outside of the home, and therefore ingest soil only while home (Appendix 3). A third scenario was developed for adults who reside at home for 30 years as homemakers or individuals self-employed at home (Appendix 5). No soil ingestion is assumed to occur during sleep or while away on a three week annual vacation. Children of ages of 1 through 17 were considered in a fourth scenario, where there is no residential soil ingestion while at school, sleeping, or away on vacations (Appendix 8). An eighteen year duration of exposure was chosen, assuming that the individuals will move away after high school graduation for reasons such as vocation, education, military service, and/or marriage. A fifth and sixth scenario was developed for ingestion of soil while using a community park (Appendix 12 and 13) or attending school (Appendix 14 and 15).

Exposure by soil ingestion according to these scenarios is summarized in Table 1.

7.3 Gastrointestinal Absorption Of DDT_{tot} From Ingested Soil

The systemic absorption of DDT_{tot} from ingested soil is assumed to be 100 percent. Other values will be considered if based on experimental data generated by accepted scientific practices.

The systemic absorption of soil-borne DDT_{tot} from ingested soil is not known. Oral absorption of p,p'-DDT from other vehicles is known to be at least 80 percent (see Smith, Section 15.3.1.2, in Hayes and Laws, 1991). Adsorption of DDT_{tot} to soil could be expected to hinder absorption somewhat. However, the effects of digestion physiology, such as displacement from soil binding sites by gastric acid or liver bile acids, solubilization of organic molecules by bile acids, or dissolution of DDT_{tot} itself by bile acids and/or dietary fat with systemic re-uptake via enterohepatic circulation, is probable. Therefore, systemic absorption of DDT_{tot} from soil is considered to be 100 percent, in order to be health-protective in the absence of laboratory data.

7.4 Contact Rate Of Soil With Skin

The default value for daily contact of soil with skin (i.e., exposure) is assumed to be 450 mg/day for a residential scenario. Other values are encouraged to be developed on a site or receptor specific basis where warranted.

There are no universally accepted values for the average daily rate of skin contact with soil. Numerous case-specific factors impact upon the daily rate of soil contact with skin. As Sedman (1989) has aptly summarized: "The surface area of skin exposed to soil, the amount of soil that adheres to the exposed skin [soil adherence factor], the type of soil particles that adhere to skin, and the distribution of these particles in soil would be expected to influence the level of dermal exposure to toxic substances in soil."

Sedman estimated an average daily exposure rate to soil of 450 mg/day for lifetime residential exposure scenario. The head, neck, lower arms, hands, and feet were assumed to be exposed on a daily basis. A soil adherence factor of 0.5 mg soil/cm^2 of skin was estimated from three data sets showing adherence values of 0.2, 0.5 and 0.9 mg/cm^2. However, soil load was assumed to decrease with age, due to differences in play-relaxation behavior paradigms with age. The dermal exposure rates thus calculated were age specific. A range of daily dermal exposure rates of 1025 mg/day for ages 1-2 to 403 mg/ dy for ages 17-18 was calculated, with ages 18 and over (adult) having rates of 360 mg/day. For a 70 year lifetime, this is equivalent to 450 mg/day.

Alternative scenarios can be calculated according to guidance provided in USEPA's "Risk Assessment Guidance for Superfund" manual (USEPA (1989a) in conjunction with exposure data given in USEPA's "Exposure Factors Handbook" (USEPA, 1989b).

A number of plausible dermal exposure scenarios were developed according to site and/or receptor-specific factors. Examples are given in the Appendices. Scenario one uses the default value of 450 mg/day for 70 years (Appendix 2). The second scenario concerns adults who work outside of the home, and therefore come in contact with residential soil and house dust only while home (Appendix 4). A third scenario was developed for adults who reside at home for 30 years as homemakers or individuals self-employed at home (Appendices 6 and 7). No dermal contact with soil is assumed to occur during sleep or while away on a three week annual vacation. Children of ages of 1 through 18 were considered in a fourth scenario, where there is no contact with residential soil while at school, sleeping, or away on vacations (Appendices 9 through 11). An eighteen year duration of exposure was chosen, assuming that the individuals will move away after high school graduation for reasons such as vocation, education, military service, and/or marriage. A fifth and sixth scenario was developed for dermal contact with soil while using a community park (Appendices 12 and 13) or attending school (Appendices 14 and 15).

Exposure to DDT_{tot} by dermal contact with soil according to these scenarios is summarized in Table 1, assuming that the concentration of DDT_{tot} in soil is 1 mg/kg.

7.5 Systemic Absorption Of Soil-Borne DDT_{tot} Across Skin

The systemic absorption of DDT_{tot} from soil in contact with exposed skin is assumed to be 5 percent of that in contact with skin per 24 hours.

The absorption of DDT from soil through skin was investigated in studies funded by TRAS (Wester et al., 1990). In live monkeys, the absorption of DDT in soil was 3.3 percent of the applied dose over a 24 hour period. That figure was 18.9 percent when acetone was used as a vehicle rather than soil. In a system using human cadaver skin, 1.0 percent of the applied dose of DDT in soil was absorbed. The percent absorption was 18.1 percent with an acetone vehicle, similar to that noted in the monkey. Earlier studies have demonstrated that the percutaneous absorption of DDT is dependent on not only the vehicle but also on the area of the body to which the mixture was applied (Feldman and Wester, 1974). Based on the results of Wester et al.

(1990) with DDT in soil along with those of earlier investigators using organic vehicles, TRAS recommends that 5 percent be used as a default figure for the systemic absorption of soil-borne DDT_{tot} from soil through skin. In other words, the dose absorbed systemically represents 5 percent of the dose administered dermally.

Note that the 5 percent dermal absorption figure is specific for DDT_{tot}. In the absence of relevant data, best professional judgement must be used for other chemicals in conjunction with existing information. For example, Smith cites the differences between the acute oral vs dermal toxicity between DDT and dieldrin. To quote Smith: "...DDT is poorly absorbed by skin from solutions, and the absorption of solid material is so poor that it is difficult or impossible to measure...In contrast, even solid dieldrin, if very finely ground, is absorbed so effectively through the skin that it is about half as toxic when applied dermally as when administered by mouth" (Smith, Section 15.2.2.1, in Hayes and Laws, 1991). Therefore, the 5 percent dermal absorption figure for DDT utilized in this Guidance Standard can not be used automatically as a default for other compounds. Note that CAPCOA and SCAQMQ (CAPCOA, 1992; and SCAQMD, 1988) proposed some generic figures for dermal absorption of volatile organic compounds, and Howd et al (1990) and Howd (1991) proposed dermal absorption values for a number of organic compounds, based on several modeling schemes.

A dermal absorption value of 4.2 percent was recently presented for soil-borne chlordane in a preliminary report (Maibach et al, 1992). This value, or one derived from the data, will be considered for use when the data are published in a peer-reviewed journal and available for independent evaluation. Until then, TRAS recommends the use of 10 percent for dermal absorption of chlordane from soil, in accordance with SCAQMD (1988) guidance for organic chemicals in general, except as modified by CAPCOA (1992) recommendations.

8 OTHER ROUTES OF EXPOSURE

8.1 Water

The examples developed in the Appendices of this document assume that there is no contamination of usable surface or ground water with DDT_{tot}. If ground and/or surface water are contaminated with DDT_{tot}, a multi-media risk assessment is necessary.

8.2 Inhalation Of Dust

The risk due to inhalation of dust containing DDT_{tot}, in a residential scenario, is insignificant. Inhalation of vapors containing DDT_{tot} would not be expected because DDT_{tot} is practically nonvolatile.

Inhalation of dust (soil) containing DDT_{tot} is a probable route of exposure, in addition to soil ingestion and skin contact with soil. However, the risks associated with inhalation of dust containing agricultural concentrations of DDT_{tot} are insignificant. Using a derivative of the USEPA (1989a) equation on page 6-44, entitled "Residential Exposure: Inhalation of airborne (Vapor Phase) Chemicals," the inhalation exposure under a reasonable worst-case residential scenario was calculated. The assumptions, calculations, and results are shown in Appendix 16. The assumptions include a 30 year exposure period in an extremely dusty location. Respirable dust is assumed to be 50 ug/m^3, a condition unlikely to be encountered around any residence on a continuous basis. The lifetime daily dose level would be 6.12×10^{-9} mg/kg-day, which poses an estimated upper bound risk of 2×10^{-9}.

8.3 Ingestion Of Home-Grown Produce

The ingestion of homegrown produce is not included in the current Guidance Standard. The high-density nature of residential development of old agricultural land in California generally precludes vegetable gardening to any meaningful degree. Moreover, the data void for plant-uptake of DDT from soil makes estimations of exposure from modeled results difficult to evaluate. Exposure via ingestion of home-grown produce, however, should be considered on a site-specific basis. Examples would include residential development in rural areas with property sizes allowing gardens, high density housing tracts having "community" garden areas, ethnic neighborhoods in which growing of produce is according to cultural dictates.

Due to the nature of high-density housing typical of new residential development of old agricultural land in California, the growing of produce in meaningful amounts is considered unlikely to occur in such tracts. Therefore, TRAS regards the ingestion of homegrown produce to be an insignificant pathway for exposure to DDT_{tot} relative to those of soil ingestion and dermal contact with soil.

However, should single-unit or low-density housing areas or tracts having community garden space be under consideration, guidance from CAPCOA (1992), USEPA (1989a, 1991a), and SCAQMD (1988) is recommended. In general, these documents provide models and/or default assumptions which can be used to estimate the uptake of chemicals from soil into plants, utilizing octanol:water partition coefficients (Kow) and organic carbon partition coefficients (Koc) for specific compounds, in conjunction with organic carbon soil content. To date, however, the model is not sufficiently validated for general use in risk assessment, e.g., to estimate the uptake of pesticides into edible portions of produce or whether the pesticides of interest actually transpose into edible portions of produce or remain sequestered in the roots.

With these caveats, one can model the plant uptake of DDT_{tot} into home-grown produce, and estimate exposure via ingestion using default assumptions provided in any of the above-mentioned four documents. Such an exercise is presented in Appendix 18, using a concentration of DDT_{tot} in the soil of 1 ppm (1 mg DDT/kg soil) as an example. Based on information in Section 2.4 of the OSWER Directive (USEPA, 1991a), updating previous assumptions (USEPA, 1989a and 1989b), the average "reasonable worst case" consumption of homegrown vegetables or fruit is 80 g/day or 42 g/day, respectively, for a total of 122 g/day. An exposure scenario for DDT based on consumption of home-grown produce is presented in Appendix 17.

Consider, however, that such an estimation is region and case-specific, and, as stated by USEPA (1989a) in Exhibit 6-18, page 6-46, that the fraction ingested ("FI") is "[a] Pathway-specific value [and] (should consider location and size of [the] contaminated area relative to that of residential areas, as well as anticipated usage patterns)." Therefore, in the opinion of TRAS, high-density tract housing would preclude the use of such reasonable worst case" estimations, or even the use of ingestion of homegrown produce itself, in the estimation of exposure to DDT in the soil.

Should such estimations be warranted due to site-specific factors, TRAS recommends that exposure and risk from consumption of homegrown produce be compared to that from consumption of commercial produce for perspective. Such a comparison can be made from data given in the U.S. Food and Drug Administration's (FDA) "Total Diet Survey," which is representative of the "average" American diet. Results from the 1988 (FDA, 1989) survey are summarized in Tables 3 and 4 , and present exposure and risk estimations for DDT_{tot}, as well as the summed risk estimations for eight other persistent organochlorine/animal carcinogen pesticides which were detected and quantitated in food.

Risk managers may use such comparisons to place into perspective site-specific situations in which the risk from homegrown produce will replace that from commercial produce.

9 RISK CHARACTERIZATION

Characterization of risk from exposure to DDT_{tot} via the soil will be conducted according to accepted methods, and be performed or approved by individuals qualified via education and experience to conduct a risk assessment.

Risk associated with exposure to DDT_{tot} in soil was calculated from the scenarios given in the Appendices, as follows:

Risk = Exposure x Slope Factor

Where:

Risk = The probability that cancer will occur to an individual exposed for a lifetime (unitless).

Exposure = "Lifetime Average Daily Dose" (LADD) in mg/kg-day. LADD is the dose of DDT_{tot} received over a specified period of time, which is then averaged over a 70 year lifetime.

Slope Factor = 0.34 (mg/kg-day)-1 = 0.34 kg-day/mg.

Then:

Risk = $LADD_{DDT}$ x 0.34 kg-day/mg

LADD is a case-specific value, and should be estimated in a manner similar to that provided for guidance in the Appendices. The following example is taken from Appendix 4 (dermal exposure):

Assume:

Concentration of DDT in soil = 1 mg DDT_{tot}/kg soil (1 ppm).

Route of exposure = Dermal contact, i.e., contact of exposed skin with soil containing DDT_{tot}.

Exposure scenario = Adults living at one residence for 30 years, but working away from the residence on 5 days per week for 49 weeks per year, as developed in Appendix 4.

$LADD_{DDT}$ = 1.88x10-7 mg DDT_{tot}/kg-day

Then:

Risk = 1.88x10-7 mg/kg-day x 0.34 kg/day-mg

= 6.4×10^{-8}

A risk of 6.4x10-8 is equivalent to 6 additional cases per hundred million individuals exposed for a lifetime. The term "additional" denotes cases which are exposure-related and occur in addition to the normal "background" cancer rate, which is approximately one individual in four which live for a 70 year lifetime.

For this document, soil was considered to be the exclusive medium of exposure because soil is typically the only medium of concern for agricultural land being used for other purposes such as high density residential development. The scenarios given as examples in the Appendices were developed assuming that DDT_{tot} was present in soil at a concentration of 1 mg DDT_{tot}/ kg soil. If the concentration of DDT_{tot} found in soil is greater or less than 1 mg/kg, the case-specific exposure and risk levels given in Tables 1 and 2 can be multiplied by that soil concentration (in mg/kg) to yield the exposure and risk levels associated with that particular concentration of DDT_{tot} in soil.

10 ACCEPTABLE RISK

For the purposes of this Guidance document, an "acceptable" risk is defined to be a risk which is no greater than $1x10^{-6}$. However, given the numerous uncertainties and conservatism in the risk assessment process, risks which are "greater" than $1x10^{-6}$ can be justified on a site-specific, receptor-specific, or regulatory-specific basis.

The level of risk which constitutes an "Acceptable Risk" is a risk management decision solely, and shall not influence the risk assessment process. Note that the risk manager/governmental health administrator must exercise flexibility in selection of an acceptable level of risk, according to case/site-specific considerations as well as relevant health concerns. A risk of "$1x10^{-6}$" represents an excess cancer prevalence not exceeding one case per million individuals exposed per lifetime. Note, however, that other California regulatory processes consider a risk level of $1x10^{-5}$ as being acceptable. Proposition 65, the Clean Water Act of 1988 (Title 26, CCR) is an example. Therefore, other criteria may be justified in defining acceptable risk of DDT_{tot} in soil on a case-specific basis.

11 SOIL REMEDIATION LEVELS

Selection of soil remediation levels involves two distinct processes:

1. The development of exposure scenarios based on either default values or case and/or receptor--specific assumptions.

2. A risk management decision, separate from the risk appraisal process, regarding what constitutes "acceptable" risk.

In order to establish soil remediation levels (SRLs), risk assessors must provide risk managers with appropriate exposure scenarios relevant to intended land use or estimations of actual receptor lifestyles. Examples of such scenarios are given in the following Appendices:

Appendices 1-7: For adults exposed to residential soil by ingestion or dermal contact.

Appendices 8-11: For children exposed to residential soil by ingestion or dermal contact.

Appendices 12 and 13: For children to soil by ingestion or dermal contact through use of a community park.

Appendices 14 and 15 : For children exposed at school.

Appendix 16: For adults exposed in a residential setting by inhalation of wind-borne soil/dust.

Appendix 17: For ingestion of home-grown produce by adults.

Then, risk managers must decide two pivotal issues:

- The appropriate exposure scenario(s), based on actual or intended land use.

- The level of risk which is acceptable for the given exposure scenario(s) and receptor population at risk.

Soil remediation levels (SRLs) can be calculated once the appropriate exposure scenarios have been developed, the total risk due to exposure from each pathway is summed, and the level of "acceptable" risk is chosen.

The exposure scenarios for DDT_{tot} located in Appendices 1-17 were developed on the assumption that DDT_{tot} was present in the soil at a concentration of 1 mg DDT_{tot}/kg soil (1 ppm). The risk values given in Table 2 were calculated from those scenarios. To calculate risk values based on other soil concentrations of DDT_{tot}, the values in Table 2 can be multiplied by the concentration of DDT_{tot}, expressed as ppm or mg DDT_{tot}/kg soil, found in soil.

11.1 Calculation

Calculation of a SRL for each scenario can be done simply, according to the following equation:

$$SRL = \frac{\text{"Acceptable" Risk}}{\text{Calculated Risk}}$$

SRLs were calculated using the exposure scenarios developed in Appendices 1-17. The results are given in Table 5. Three are shown below for illustration:

11.2 Example One: Adult Residential Default

The following default assumptions are used: lifetime exposure for 70 years, soil ingestion of 100 mg/day, dermal contact with soil is 450 mg/day, and a dermal absorption factor of 5 percent of soil-borne DDT through the skin. The soil concentration of DDT_{tot} in these examples is assumed to be 1 ppm (1 mg DDT/kg soil) which is the soil concentration value used for development of risk values given in Table 2, using the soil ingestion exposure scenario from Appendix 1 in conjunction with the dermal exposure soil scenario developed in Appendix 2. The summed risk from each pathway (Table 2) is 6.0×10^{-7}. Assuming that risk management determines that 1×10^{-5} is an acceptable level of individual risk, the case specific SRL for a 1×10^{-5} risk can be calculated as follows:

$$\text{SRL} = \frac{1 \times 10^{-5}}{6.0 \times 10^{-7}} = 16.7 \text{ mg DDT/kg soil} = 16.9 \text{ ppm}$$

If risk management were to determine that the acceptable risk level was 1×10^{-6} rather than 1×10^{-5}, then the SRL would be reduced by a factor of 10, to 1.7 mg DDT/kg soil, or 1 .7 ppm. Such a calculation was performed by this author for a presentation delivered at the Society of Toxicology meeting in February, 1991, by Liao et al.(1991).

11.3 Example Two: Adult Residential For 30 Years

SRLs were calculated for scenarios with adults who stay at home as homemakers or individuals employed at home, and live there for 30 years. The soil ingestion and dermal contact exposure scenarios given in Appendices 5 or 7, respectively, were used in this example. The combined risk from each pathway, associated with DDT_{tot} in soil (Table 2) is 4.6×10^{-7}. Assuming that risk management determines that 1×10^{-5} is an acceptable level of individual risk, the case specific SRL is as follows:

$$\text{SRL} = \frac{1 \times 10^{-5}}{4.6 \times 10^{-7}} = 21.7 \text{ mg DDT/kg soil} = 21.7 \text{ ppm}$$

If risk management were to determine that the acceptable risk level was 1×10^{-6} rather than 1×10^{-5}, then the SRL would be reduced by a factor of 10, to 2.2 mg DDT/kg soil, or 2 .2 ppm.

11.4 Example Three: Children Living Wi th Parents

In this example, SRLs were calculated for scenarios with children who live with their parents from birth to age 18, and then move out. The soil ingestion and dermal contact exposure scenarios given in Appendices 8 or 11, respectively, were used in this example. The combined risk from each pathway, associated with a DDT_{tot} soil at a concentration of 1 mg DDT_{tot}/kg soil, is 7.0×10^{-7} (Table 2). Assuming that risk management determines that 1×10^{-5} is an acceptable level of individual risk, the case specific SRL is as follows:

$$SRL = \frac{1 \times 10^{-5}}{7.0 \times 10^{-7}} = 14.3 \text{ mg DDT/kg soil} = 14.3 \text{ ppm}$$

If risk management were to determine that the acceptable risk level was 1×10^{-6} rather than 1×10^{-5}, then the SRL would be reduced by a factor of 10, to 1.4 mg DDT/kg soil, or 1 .4 ppm.

11.5 Caveat

The SRLs listed above and in Table 5 are CASE-SPECIFIC for the exposure scenarios developed in the Appendices. They are examples only, are NOT intended for generic use, and should NOT be considered as generic "action levels" for soil remediation. SRLs must be developed on a case-specific basis, according to case-specific assumptions and parameters regarding exposure, as shown by the examples given in the Appendices.

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TABLE 1

SUMMARY OF RESIDENTIAL EXPOSURE TO DDT IN SOIL*

Scenario	Lifetime Average Daily Dose (mg/kg-day) Ingestion	Dermal	Total
RESIDENTIAL ADULT			
Seventy Year (Default)	1.43×10^{-6}	3.21×10^{-7}	1.75×10^{-6}
Thirty Year - Works Away From Home	3.29×10^{-7}	1.88×10^{-7}	5.17×10^{-7}
Thirty Year - Homemaker or Works at Home (Typical Case)	5.34×10^{-7}	3.06×10^{-7}	8.40×10^{-7}
Thirty Year - Homemaker or Works at Home ("High Exposure Level")	5.34×10^{-7}	8.21×10^{-7}	1.36×10^{-6}
Inhalation of Soil	N/A**	N/A	6.12×10^{-9}
Ingestion of Home-grown Produce	N/A	N/A	8.40×10^{-6}
RESIDENTIAL CHILDREN, AGES 1 THROUGH 17			
Typical Case	1.17×10^{-6}	2.70×10^{-7}	1.44×10^{-6}
"High Exposure" Scenario Case One	1.17×10^{-6}	4.47×10^{-7}	1.62×10^{-6}
"High Exposure" Scenario Case Two	1.17×10^{-6}	8.86×10^{-7}	2.06×10^{-6}
COMMUNITY PARK, AGES 1 THROUGH 17	1.29×10^{-7}	6.52×10^{-8}	1.94×10^{-7}
SCHOOL, AGES 6 THROUGH 17	1.12×10^{-7}	1.24×10^{-8}	1.24×10^{-7}

* Assumes that concentration of DDT_{tot} in soil is 1 mg DDT_{tot}/kg soil (1 ppm).

** N/A = Not applicable

TABLE 2

SUMMARY OF RISK FROM RESIDENTIAL EXPOSURE TO DDT IN SOIL*

Scenario	Lifetime Excess Cancer Risk Ingestion	Dermal	Total
RESIDENTIAL ADULT			
Seventy Year (Default)	$4.9x10^{-7}$	$1.1x10^{-7}$	$6.0x10^{-7}$
Thirty Year - Works Away From Home	$1.1x10^{-7}$	$6.4x10^{-8}$	$1.7x10^{-7}$
Thirty Year - Homemaker or Works at Home Typical Case	$1.8x10^{-7}$	$1.0x10^{-7}$	$2.8x10^{-7}$
Thirty Year - Homemaker or Works at Home "High Exposure Level"	$1.8x10^{-7}$	$2.8x10^{-7}$	$4.6x10^{-7}$
Inhalation of Soil	N/A**	N/A	$2.1x10^{-9}$
Ingestion of Home-grown Produce	N/A	N/A	$2.9x10^{-6}$
RESIDENTIAL CHILDREN, AGES 1 THROUGH 17			
Typical Case	$4.0x10^{-7}$	$9.2x10^{-8}$	$4.9x10^{-7}$
"High Exposure" Scenario Case One	$4.0x10^{-7}$	$1.5x10^{-7}$	$5.5x10^{-7}$
"High Exposure" Scenario Case Two	$4.0x10^{-7}$	$3.0x10^{-7}$	$7.0x10^{-7}$
COMMUNITY PARK, AGES 1 THROUGH 17	$4.4x10^{-8}$	$2.2x10^{-8}$	$6.6x10^{-8}$
SCHOOL, AGES 6 THROUGH 17	$3.8x10^{-8}$	$4.2x10^{-9}$	$4.2x10^{-8}$

* Assumes that concentration of DDT_{tot} in soil is 1 mg DDT_{tot}/kg soil (1 ppm).

** N/A = Not applicable

TABLE 3

FOOD AND DRUG ADMINISTRATION TOTAL DIET STUDY EXPOSURE TO ORGANOCHLORINE PESTICIDES IN FOOD*

	Pesticide Consumption (mg/kg-day)		
	Infants (6-11 months)	**Teenagers** (14-16 years)	**Seniors** (60-65 years)
BHC-alpha and beta[a]	0.8×10^{-6}	1.4×10^{-6}	1.0×10^{-6}
BHC-gamma (lindane)	0.8×10^{-6}	1.4×10^{-6}	0.9×10^{-6}
Chlordane	0.7×10^{-6}	0.7×10^{-6}	1.0×10^{-6}
DDT[b]	68.1×10^{-6}	26.4×10^{-6}	11.5×10^{-6}
Dieldrin	11.4×10^{-6}	4.9×10^{-6}	3.9×10^{-6}
Heptachlor[c]	4.0×10^{-6}	1.7×10^{-6}	0.7×10^{-6}
Hexachlorobenzene	1.6×10^{-6}	1.1×10^{-6}	0.6×10^{-6}
Toxaphene	8.7×10^{-6}	7.8×10^{-6}	11.6×10^{-6}

* Assumes consumption of commercial produce.

a BHC = benzene hexachloride

b Sum of DDT, DDD, and DDE

c Sum of heptachlor and heptachlor epoxide

TABLE 4

FOOD AND DRUG ADMINISTRATION TOTAL DIET STUDY RISK FROM CONSUMPTION OF ORGANOCHLORINE PESTICIDES IN FOOD*

	Excess Cancer Risk		
	Infants (6-11 months)	**Teenagers (14-16 years)**	**Seniors (60-65 years)**
BHC-alpha and betaa	3.0x10-6	5.3x10-6	3.8x10-6
BHC-gamma (lindane)	1.0x10-6	1.8x10-6	1.2x10-6
Chlordane	9.0x10-7	9.0x10-7	1.3x10-6
DDTb	2.3x10-5	9.0x10-6	3.9x10-6
Dieldrin	1.8x10-4	7.8x10-5	6.2x10-5
Heptachlorc	2.7x10-5	1.2x10-5	4.8x10-6
Hexachlorobenzene	2.6x10-6	1.8x10-6	1.0x10-6
Toxaphene	9.6x10-6	8.6x10-6	1.3x10-5
Sum of Risk	2.5x10-4	1.2x10-4	9.1x10-5

Arithmetic Mean - All Groups: 1.5×10^{-4}

* Assumes consumption of commercial produce.

a BHC = benzene hexachloride (slope factor used is average of both)

b Sum of DDT, DDD, and DDE (slope factor used is for DDT)

c Sum of heptachlor and heptachlor epoxide (slope factor used is average of both)

TABLE 5

SITE SPECIFIC SOIL REMEDIATION LEVELS (SRLs) CALCULATED FROM EXPOSURE SCENARIOS IN THE APPENDICES

SCENARIO	RISK[a] ->	SRL (ppm) at Risk Determined to be "Acceptable"		
		$1x10^{-6}$	$5x10^{-6}$	$1x10^{-5}$
RESIDENTIAL ADULT				
Seventy Year (Default)	$6.0x10^{-7}$	1.67	8.3	16.7
Thirty Year - Works Away From Home	$1.7x10^{-7}$	5.88	29.4	58.8
Thirty Year – Homemaker or Works at Home Typical Case	$2.8x10^{-7}$	3.57	17.9	35.7
Thirty Year - Homemaker or Works at Home "High Exposure Level"	$4.6x10^{-7}$	2.17	10.9	21.7
Ingestion of Home-grown Produce	$2.9x10^{-6}$	0.34	1.7	3.4
RESIDENTIAL CHILDREN, AGES 1 THROUGH 18				
Typical Case	$4.9x10^{-7}$	2.04	10.2	20.4
"High Exposure" Scenario Case One	$5.5x10^{-7}$	1.82	9.1	18.2
"High Exposure" Scenario Case Two	$7.0x10^{-7}$	1.42	7.1	14.2
COMMUNITY PARK, CHILDREN, AGES 1 THROUGH 17	$6.6x10^{-8}$	15.15	75.8	151.5
SCHOOL, AGES 6 THROUGH 17	$4.2x10^{-8}$	23.81	119.0	238.1

[a] Total risk values taken from Table 2.

APPENDIX 1

RESIDENTIAL SOIL INGESTION
ADULT
DEFAULT LIFETIME EXPOSURE

1 ASSUMPTIONS

1.1 Adults live at residence for 70 years.
1.2 Time spent at residence is 24 hours/day, 7 days/week, 52 weeks/year, for an entire 70 year lifetime.
1.3 Soil ingestion rate for adults is 100 mg/day (USEPA, 1989a, Page 6-40).
1.4 Fraction of DDT_{tot} which is absorbed systemically from ingested soil is 1.0, i.e., 100 percent. One-hundred percent oral absorption of soil-borne DDT_{tot} is assumed, in the absence of experimental information obtained with soil as the medium of exposure.
1.5 Body weight value of adult is 70 kg (USEPA, 1989a, Page 6-40).
1.6 Concentration of DDT_{tot} in soil = 1 ppm = 1 mg DDT_{tot}/kg soil.
1.7 Exposure to contaminated soil occurs only while adult is awake and at home. Adult is always home.

2 CALCULATIONS

Calculations were based on the following equation adapted from USEPA (USEPA, 1989a, Page 6-40):

$$\text{Intake} = \frac{CS \times CF \times IR \times FI \times ABS \times EF \times ED}{BW \times AT}$$

Where:

Intake = Daily dose of DDT_{tot} averaged over a lifetime, in mg/kg-day. Also known as "Lifetime Average Daily Dose" (LADD).
CS = DDT_{tot} concentration in soil, in mg DDT_{tot}/kg soil
CF = Conversion factor = 10-6 kg/mg
IR = Soil ingestion rate, in mg soil/day
ABS = Fraction of soil-borne DDT_{tot} absorbed systemically (unitless), i.e., percent absorbed/100.
FI = Fraction of soil per day coming from contaminated source (unitless). Assumes soil ingestion occurs only while receptors are awake, and the residence is the only contaminated area of interest.
EF = Exposure frequency in days per year, i.e., "days/week x weeks/year."
ED = Exposure duration in years.
BW = Body weight in kilograms.

AT = Averaging time: period over which exposure is averaged, in days. For carcinogens, AT typically is a human lifetime in days, which is "365 days/year x 70 years."

Calculation of "Intake" is as follows:

Where:

FI = 1.0, because the total source of contaminated soil is the residence.
EF = 365 days/year
ED = 70 years
AT = 365 days/year x 70 years

These cancel out as follows:

$$\frac{FI \times EF \times ED}{AT} = \frac{1.0 \times 365 \text{ days/year} \times 70 \text{ years}}{365 \text{ days/year} \times 70 \text{ years}} = 1.0$$

The remaining equation becomes:

$$\text{Intake} = \frac{CS \times CF \times IR \times ABS}{BW}$$

Where:

CS = 1 mg DDT_{tot}/kg soil
CF = 10-6 kg/mg
IR = 100 mg soil/day
ABS = 1.0
BW = 70 kg body weight

Then Intake ("LADD"):

$$\text{Intake} = \frac{1 \text{ mg } DDT_{tot}\text{/kg soil} \times 10^{-6} \text{ kg/mg} \times 100 \text{ mg soil/day} \times 1.0}{70 \text{ kg}}$$

$$= 1.43 \times 10^{-6} \text{ mg } DDT_{tot}\text{/kg-day}$$

APPENDIX 2

RESIDENTIAL DERMAL SOIL EXPOSURE
ADULT
DEFAULT LIFETIME EXPOSURE

1 ASSUMPTIONS

1.1 Adults live at residence for 70 years.
1.2 Time spent at residence is 24 hours/day, 7 days/week, 52 weeks/year, for an entire 70 year lifetime.
1.3 Rate of soil contact with skin is 450 mg/day (Sedman, 1989).
1.4 Fraction of soil-borne DDT_{tot} which is absorbed systemically through the skin in 24 hours (dermal absorption) 0.05, i.e., 5 percent. Five percent dermal absorption of soil-borne DDT_{tot} is based on the data of Wester et al. (1990).
1.5 Body weight value of adult is 70 kg (USEPA, 1989a, Page 6-40).
1.6 Concentration of DDT_{tot} in soil = 1 ppm = 1 mg DDT_{tot}/kg soil.
1.7 Exposure to contaminated soil occurs only while adult is awake and at home. Adult is always home.

2 CALCULATIONS

Calculations were based on the following equation adapted from USEPA (USEPA, 1989a, Page 6-41):

$$\text{Absorbed Dose} = \frac{CS \times CF \times SA \times AF \times ABS \times FI \times EF \times ED}{BW \times AT}$$

Where:

Absorbed Dose = Daily dose of DDT_{tot} averaged over a lifetime, in mg/kg-day. Also known as "Lifetime Average Daily Dose."
CS = DDT_{tot} concentration in soil, in mg DDT_{tot}/kg soil
CF = Conversion factor = 10-6 kg/mg
SA = Surface area of skin exposed to soil = cm^2 skin/day
AF = Adherence factor of soil to skin = mg soil/cm^2 skin
ABS = Fraction of soil-borne DDT_{tot} absorbed systemically (unitless), i.e., percent absorbed/100.
FI = Fraction of soil per day coming from contaminated source (unitless). Assumes skin contact occurs only while receptors are awake, and the residence is the only contaminated area of interest.
EF = Exposure frequency in days per year, i. e., "days/week x weeks/year."

ED = Exposure duration in years
BW = Body weight in kilograms
AT = Averaging time: period over which exposure is averaged, in days. For carcinogens, AT typically is a human lifetime in days, which is "365 days/year x 70 years."

Calculation of "Absorbed Dose" is as follows:

Where:
FI = 1.0, because the total source of contaminated soil is at the residence.
EF = 365 days/year
ED = 70 years
AT = 365 days/year x 70 years

These cancel out as follows:

$$\frac{FI \times EF \times ED}{AT} = \frac{1.0 \times 365 \text{ days/year} \times 70 \text{ years}}{365 \text{ days/year} \times 70 \text{ years}} = 1.0$$

The remaining equ ation becomes:

$$\text{Absorbed Dose} = \frac{CS \times CF \times SA \times AF \times ABS}{BW}$$

Where:
$CS = 1$ mg DDT_{tot}/kg soil
CF = 10-6 kg/mg
SA x AF = 450 mg/day, by default
ABS = 0.05
BW = 70 kg body weight

Then:

$$\text{Absorbed Dose} = \frac{1 \text{ mg } DDT_{tot}\text{/kg soil} \times 10^{-6} \text{ kg/mg} \times 450 \text{ mg soil/day} \times 0.05}{70 \text{ kg}}$$

$$= 0.321\times10^{-6} \text{ mg } DDT_{tot}\text{/kg-day}$$

APPENDIX 3

RESIDENTIAL SOIL INGESTION
ADULT FOR 30 YEARS
WORKS AWAY FROM HOME

1 ASSUMPTIONS

1.1 Adults live at residence for 30 years, but are away from home on a periodic basis.

1.2 Time spent at residence:

1.2.1 Weekdays: At work for 8 hours/day, 5 days/week, for 49 weeks/year, and at home 16 hours/day, 5 days/week, for 49 weeks/year.

1.2.2 Weekends: At home 20 hours/day, 2 days/week, for 49 weeks/year.

1.2.3 Vacations: Away from home 24 hours/day for 3 weeks/year.

1.3 Soil ingestion rate for adults is 100 mg/day (USEPA , 1989a, Page 6-40).

1.4 Fraction of DDT_{tot} which is absorbed systemically from ingested soil is 1.0, i.e., 100 percent. One-hundred percent oral absorption of soil-borne DDT_{tot} is assumed, in the absence of experimental information obtained with soil as the medium of exposure.

1.5 Body weight value of adult is 70 kg (USEPA, 1989a, Page 6-40).

1.6 Concentration of DDT_{tot} in soil = 1 ppm = 1 mg DDT_{tot}/kg soil.

1.7 Exposure to contaminated soil occurs only while adult is awake and at home.

2 CALCULATIONS

Calculations were based on the following equation adapted from USEPA (USEPA, 1989a, Page 6-40):

$$\text{Intake} = \frac{CS \times CF \times IR \times ABS \times FI \times EF \times ED}{BW \times AT}$$

Where:

Intake = Daily dose of DDT_{tot} averaged over a lifetime, in mg/kg-day. Also known as "Lifetime Average Daily Dose" (LADD).

CS = DDT_{tot} concentration in soil, in mg DDT_{tot}/kg soil

CF = Conversion factor = 10-6 kg/mg

IR = Soil ingestion rate, in mg soil/day

ABS = Fraction of soil-borne DDT_{tot} absorbed systemically (unitless), i.e., percent absorbed/100.

FI = Fraction of soil per day coming from contaminated source (unitless). Assumes soil ingestion occurs only while receptors are awake, and the residence is the only contaminated area of interest.

EF = Exposure frequency in days per year, i.e., "days/week x weeks/year."

ED = Exposure duration in years

BW = Body weight in kilograms

AT = Averaging time: period over which exposure is averaged, in days. For carcinogens, AT typically is a human lifetime in days, which is "365 days/year x 70 years."

Calculation of "Intake" was broken up into several components, for simplifying exposure calculations, as follows:

1. First, the total period of exposure, in days, was calculated, as follows:

FI x EF x ED = Total Days Exposed

The "Total Days Exposed" was calculated for an adult living at a residence for a total of 30 years, but leaving the home to work for 8 hours/day, 5 days/week, 49 weeks/year, as follows:

Where:

FI = hours exposed/hours awake per day

EF = days/week x weeks/year exposed

ED = duration of exposure period, in years.

Weekday Exposure:

FI = hours at home awake/total hours awake. Time awake is 16 hours/day, with 8 hours/day spent away from home at work. Therefore, the time spent at home awake = 16-8 = 8 hours/day, and FI = 8 hours home/16 hours awake.

EF = weekdays home/week x weeks home/year, i.e., 5 days/week x 49 weeks/year.

ED = 30 years.

The "Total Weekdays Exposed" is as follows:

8 hours/16 hours x 5 days/week x 49 weeks/year x 30 years = 3,675 Days

Weekend Exposure:

FI = hours at home awake/total hours awake. Time awake is 16 hours/day, with 4 hours/day spent away from home for shopping, errands, or recreation. Therefore, the time spent at home awake = 16-4 = 12 hours/day, and FI = 12 hours home/16 hours awake.

EF = weekend days home/week x weeks home/year, i.e., 2 days/week x 49 weeks/year.

ED = 30 years.

The "Total Weekend Days Exposed" is as follows:

12 hours/16 hours x 2 days/week x 49 weeks/year x 30 years = 2,205 Days

Total Days Exposed = Weekdays + Weekends
= 3,675 days + 2,205 days
= 5,880 days

2. "Total Soil Dose" is then calculated, as follows:

$$\text{Total Soil Dose} = \frac{\text{Total Days Exposed x IR}}{\text{BW}}$$

Where:

Total Days Exposed = 5,880 days
IR = 100 mg/day
BW = 70 kg

$$\text{Total Soil Dose} = \frac{\text{5,880 days x 100 mg soil/day}}{\text{70 kg}}$$

= 8,400 mg soil/kg body weight

3. This dose of soil averaged over a lifetime ("Lifetime Average Daily Dose of Soil;" $LADD_{soil}$) is calculated as follows:

$$LADD_{soil} = \frac{\text{Total Soil Dose}}{\text{AT}}$$

Where:

Total Soil Dose = 8,400 mg soil/kg body weight
AT = 365 days/year x 70 years

$$LADD_{soil} = \frac{\text{8,400 mg soil/kg body weight}}{\text{365 days/year x 70 years}}$$

= 0.329 mg soil/kg body weight-day

4. The absorbed dose of DDT_{tot} averaged over a lifetime ("Lifetime Average Daily Dose of DDT_{tot}; $LADD_{DDT}$) is as follows:

$$LADD_{DDT} = LADD_{soil} \text{ x CS x CF x ABS}$$

Where:

$LADD_{soil}$ = 0.329 mg soil/kg body weight
CS = 1 mg DDT_{tot}/kg soil
CF = 10-6 kg/mg
ABS = 1.0

$LADD_{DDT}$ = 0.329 mg soil/kg-day x 1 mg DDT_{tot}/kg soil x 10-6 kg/mg x 1.0

= 0.329x10-6 mg DDT_{tot}/kg-day

= 3.29x10-7 mg DDT_{tot}/kg-day

Note, in this example, that $LADD_{DDT}$ is equivalent to "Intake" in the equation adapted from USEPA.

APPENDIX 4

RESIDENTIAL DERMAL SOIL EXPOSURE
ADULT FOR 30 YEARS
WORKS AWAY FROM HOME

1 ASSUMPTIONS

1.1 Adult lives at residence for 30 years, but is away from home on a periodic basis.
1.2 Time spent at residence:
 1.2.1 Weekdays: At work for 8 hours/day, 5 days/week, for 49 weeks/year, and at home 16 hours/day, 5 days/week, for 49 weeks/year.
 1.2.2 Weekends: At home 20 hours/day, 2 days/week, for 49 weeks/year.
 1.2.3 Vacations: Away from home 24 hours/day for 3 weeks/year.
1.3 Body parts exposed to soil are head and hands, with surface area of 2290 cm^2, males and females combined (USEPA, 1989b, Page 4-11)
1.4 Factor for adherence of soil to skin = 0.5 mg soil/cm^2 (see Sedman, 1989, or discussion).
1.5 Fraction of soil-borne DDT_{tot} which is absorbed systemically through the skin in 24 hours (dermal absorption) is 0.05, i.e., 5 percent. Five percent dermal absorption of soil-borne DDT_{tot} is based on the data of Wester et al (1990).
1.6 Body weight value of adult is 70 kg (USEPA, 1989a, Page 6-40).
1.7 Concentration of DDT_{tot} in soil = 1 ppm = 1 mg DDT_{tot}/kg soil.
1.8 Exposure to contaminated occurs only while adult is awake and at home.

2 CALCULATIONS

Calculations were based on the following equation adapted from USEPA (USEPA, 1989a, Page 6-41):

$$\text{Absorbed Dose} = \frac{CS \times CF \times SA \times AF \times ABS \times FI \times EF \times ED}{BW \times AT}$$

Where:

Absorbed Dose = Daily dose of DDT_{tot} averaged over a lifetime, in mg/kg-day. Also known as "Lifetime Average Daily Dose" (LADD).
CS = DDT_{tot} concentration in soil, in mg DDT_{tot}/kg soil
CF = Conversion factor = 10-6 kg/mg
SA = Surface area of skin exposed to soil = cm^2 skin/day
AF = Adherence factor of soil to skin = mg soil/cm^2 skin
ABS = Fraction of soil-borne DDT_{tot} absorbed systemically (unitless), i.e.,

percent absorbed/100.

FI = Fraction of soil per day coming from contaminated source (unitless). Assumes skin contact occurs only while receptors are awake, and the residence is the only contaminated area of interest.

EF = Exposure frequency in days per year , i.e., "days/week x weeks/year."

ED = Exposure duration in years

BW = Body weight in kilograms

AT = Averaging time: period over which exposure is averaged, in days. For carcinogens, AT typically is a human lifetime in days, which is "365 days/year x 70 years."

Calculation of "Absorbed Dose" was broken up into several components, for simplifying exposure calculations, as follows:

1. First, the total period of exposure, in days, was calculated, as follows:

FI x EF x ED = Total Days Exposed

The "Total Days Exposed" was calculated for an adult living at a residence for a total of 30 years, but leaving the home to work for 8 hours/day, 5 days/week, 49 weeks/year, as follows:

Where:

FI = hours exposed/hours awake per day

EF = days/week x weeks/year exposed

ED = duration of exposure period, in years.

Weekday Exposure:

FI = hours at home awake/total hours awake. Time awake is 16 hours/day, with 8 hours/day spent away from home at work. Therefore, the time spent at home awake = 16-8 = 8 hours/day, and FI = 8 hours home/16 hours awake.

EF = weekdays home/week x weeks home/year, i.e., 5 days/week x 49 weeks/year.

ED = 30 years.

The "Total Weekdays Exposed" is as follows:

8 hours/16 hours x 5 days/week x 49 weeks/year x 30 years = 3,675 Days

Weekend Exposure:

FI = hours at home awake/total hours awake. Time awake is 16 hours/day, with 4 hours/day spent away from home for shopping, errands, or recreation. Therefore, the time spent at home awake = 16-4 = 12 hours/day, and FI = 12 hours home/16 hours awake.

EF = weekend days home/week x weeks home/year, i.e., 2 days/week x 49 weeks/year.

ED = 30 years.

The "Total Weekend Days Exposed" is as follows:

12 hours/16 hours x 2 days/week x 49 weeks/year x 30 years = 2,205 Days

Total Days Exposed = Weekdays + Weekends
= 3,675 days + 2,205 days
= 5,880 days

2. "Total Soil Dose" is then calculated, as follows:

$$\text{Total Soil Dose} = \frac{\text{Total Days Exposed x SA x AF}}{\text{BW}}$$

Where:

Total Days Exposed = 5,880 days
SA = 2290 cm^2 soil/day
AF = 0.5 mg soil/cm^2 skin
BW = 70 kg

$$\text{Total Soil Dose} = \frac{5{,}880 \text{ days x } 2290 \text{ cm}^2 \text{ skin/day x } 0.5 \text{ mg soil/cm}^2 \text{ skin}}{70 \text{ kg}}$$

= 96,180 mg soil/kg body weight

3. This dose of soil averaged over a lifetime ("Lifetime Average Daily Dose of Soil;" $LADD_{soil}$) is calculated as follows:

$$LADD_{soil} = \frac{\text{Total Soil Dose}}{\text{AT}}$$

Where:

Total Soil Dose = 96,180 mg soil/kg body weight
AT = 365 days/year x 70 years

$$LADD_{soil} = \frac{96{,}180 \text{ mg soil/kg body weight}}{365 \text{ days/year x } 70 \text{ years}}$$

= 3.764 mg soil/kg body weight-day

4. The absorbed dose of DDT_{tot} averaged over a lifetime ("Lifetime Average Daily Dose of DDT_{tot}; $LADD_{DDT}$) is as follows:

$$LADD_{DDT} = LADD_{soil} \times CS \times CF \times ABS$$

Where:

$LADD_{soil}$ = 3.764 mg soil/kg body weight
CS = 1 mg DDT_{tot}/kg soil
CF = 10-6 kg/mg
ABS = 0.05

$$LADD_{DDT} = 3.764 \text{ mg soil/kg-day} \times 1 \text{ mg } DDT_{tot}\text{/kg soil} \times 10\text{-}6 \text{ kg/mg} \times 0.05$$

$$= 0.188\text{x}10\text{-}6 \text{ mg } DDT_{tot}\text{/kg-day}$$

$$= 1.88\text{x}10\text{-}7 \text{ mg } DDT_{tot}\text{/kg-day}$$

Note, in this example, that $LADD_{DDT}$ is equivalent to "Absorbed Dose" in the USEPA equation above.

APPENDIX 5

RESIDENTIAL SOIL INGESTION
ADULT FOR 30 YEARS
HOMEMAKER OR EMPLOYED AT HOME

1 ASSUMPTIONS

1.1 Adults live at residence for 30 years.
1.2 Time spent at residence:
  1.2.1 Weekdays: At home 24 hours/day, 5 days/week, for 49 weeks/year.
  1.2.2 Weekends: At home 20 hours/day, 2 days/week, for 49 weeks/year.
  1.2.3 Vacations: Away from home 24 hours/day for 3 weeks/year.
1.3 Soil ingestion rate for adults is 100 mg/day (USEPA, 1989a, Page 6-40).
1.4 Fraction of DDT_{tot} which is absorbed systemically from ingested soil is 1.0, i.e., 100 percent. One hundred percent oral absorption of soil-borne DDT_{tot} is assumed, in the absence of experimental information obtained with soil as the medium of exposure.
1.5 Body weight value of adult is 70 kg (USEPA, 1989a, Page 6-40).
1.6 Concentration of DDT_{tot} in soil = 1 ppm = 1 mg DDT_{tot}/kg soil.
1.7 Exposure to contaminated soil occurs only while adults are awake and at home.

2 CALCULATIONS

Calculations were based on the following equation adapted from USEPA (USEPA, 1989a, Page 6-40):

$$\text{Intake} = \frac{CS \times CF \times IR \times ABS \times FI \times EF \times ED}{BW \times AT}$$

Where:

Intake = Daily dose of DDT_{tot} averaged over a lifetime, in mg/kg-day. Also known as "Lifetime Average Daily Dose."
CS = DDT_{tot} concentration in soil, in mg DDT_{tot}/kg soil
CF = Conversion factor = 10-6 kg/mg
IR = Soil ingestion rate, in mg soil/day
ABS = Fraction of soil-borne DDT_{tot} absorbed systemically (unitless), i.e., percent absorbed/100.
FI = Fraction of soil per day coming from contaminated source (unitless). Assumes soil ingestion occurs only while receptors are awake, and the residence is the only contaminated area of interest.
EF = Exposure frequency in days per year, i.e., "days/week x weeks/year."
ED = Exposure duration in years

BW = Body weight in kilograms
AT = Averaging time: period over which exposure is averaged, in days. For carcinogens, AT typically is a human lifetime in days, which is "365 days/year x 70 years."

Calculation of "Intake" was broken up into several components, for simplifying exposure calculations, as follows:

1. First, the total period of exposure, in day s, was calculated, as follows:

   FI x EF x ED = Total Days Exposed

   The "Total Days Exposed" was calculated for an adult living at a residence for a total of 30 years, and staying home daily as a homemaker or for employment within the home or on the residence property.

Where:
FI = hours exposed/hours awake per day.
EF = days/week x weeks/year exposed.
ED = duration of exposure period, in years.

Weekday Exposure:
FI = hours at home awake/total hours awake. T ime awake is 16 hours/day, with all 16 hours/day spent at home. Therefore, FI = 16 hours home awake/16 hours awake. EF = weekdays home/week x weeks home/year, i.e., 5 days/week x 49 weeks/year.
ED = 30 years.

The "Total Weekdays Exposed" is as foll ows:
16 hours/16 hours x 5 days/week x 49 weeks/year x 30 years = 7,350 Days

Weekend Exposure:
FI = hours at home awake/total hours awake. Time awake is 16 hours/day, with 4 hours/day spent away from home for shopping, errands, or recreation. Therefore, the time spent at home = 16-4 = 12 hours/day, and FI = 12 hours home awake/16 hours awake.
EF = weekend days home/week x weeks home/year, i.e., 2 days/week x 49 weeks/year.
ED = 30 years.

The "Total Weekend Days Exposed" is as follows:
12 hours/16 hours x 2 days/week x 49 weeks/year x 30 years = 2,205 Days

Total Days Exposed = Weekdays + Weekends
= 7,350 days + 2,205 days
= 9,555 days

2. "Total Soil Dose" is then calculated, as follows:

$$\text{Total Soil Dose} = \frac{\text{Total Days Exposed x IR}}{\text{BW}}$$

Where:

Total Days Exposed = 9,555 days
IR = 100 mg/day
BW = 70 kg

$$\text{Total Soil Dose} = \frac{\text{9,555 days x 100 mg soil/day}}{\text{70 kg}}$$

$$= \text{13,650 mg soil/kg body weight}$$

3. This dose of soil averaged over a lifetime ("Lifetime Average Daily Dose of Soil;" $LADD_{soil}$) is calculated as follows:

$$LADD_{soil} = \frac{\text{Total Soil Dose}}{\text{AT}}$$

Where:

Total Soil Dose = 13,650 mg soil/kg body weight
AT = 365 days/year x 70 years

$$LADD_{soil} = \frac{\text{13,650 mg soil/kg body weight}}{\text{365 days/year x 70 years}}$$

$$= \text{0.534 mg soil/kg body weight-day}$$

4. The absorbed dose of DDT_{tot} averaged over a lifetime ("Lifetime Average Daily Dose of DDT_{tot}; $LADD_{DDT}$) is as follows:

$$LADD_{DDT} = LADD_{soil} \text{ x CS x CF x ABS}$$

Where:

$LADD_{soil}$ = 0.534 mg soil/kg body weight
CS = 1 mg DDT_{tot}/kg soil
CF = 10-6 kg/mg
ABS = 1.0

$$LADD_{DDT} = 0.534 \text{ mg soil/kg-day x 1 mg } DDT_{tot}\text{/kg soil x 10-6 kg/mg x 1.0}$$

$$= 0.534\text{x}10\text{-}6 \text{ mg } DDT_{tot}\text{/kg-day}$$

$$= 5.34\text{x}10\text{-}7 \text{ mg } DDT_{tot}\text{/kg-day}$$

Note, in this example, that $LADD_{DDT}$ is equivalent to "Intake" in the equation adapted from USEPA.

APPENDIX 6

RESIDENTIAL DERMAL SOIL EXPOSURE
ADULT FOR 30 YEARS
HOMEMAKER OR EMPLOYED AT HOME

1 ASSUMPTIONS

1.1 Adults live at residence for 30 years.
1.2 Time spent at residence:
1.2.1 Weekdays: At home 24 hours/day, 5 days/week, for 49 weeks/year.
1.2.2 Weekends: At home 20 hours/day, 2 days/week, for 49 weeks/year.
1.2.3 Vacations: Away from home 24 hours/day for 3 weeks/year.
1.3 Body parts exposed to soil are head and hands, with surface area of 2290 cm^2, males and females combined (USEPA, 1989b, Page 4-11)
1.4 Factor for adherence of soil to skin = 0.5 mg soil/cm^2 (see Sedman, 1989, for discussion).
1.5 Fraction of soil-borne DDT_{tot} which is absorbed systemically through the skin in 24 hours (dermal absorption) is 0.05, i.e., 5 percent. Five percent dermal absorption of soil-borne DDT_{tot} is based on the data of Wester et al (1990).
1.6 Body weight value of adult is 70 kg (USEPA, 1989a, Page 6-40).
1.7 Concentration of DDT_{tot} in soil = 1 ppm = 1 mg DDT_{tot}/kg soil.
1.8 Exposure to contaminated soil occurs only while adults are awake and at home.

2 CALCULATIONS

Calculations were based on the following equation adapted from USEPA (USEPA, 1989a, Page 6-41):

$$\text{Absorbed Dose} = \frac{CS \times CF \times SA \times AF \times ABS \times FI \times EF \times ED}{BW \times AT}$$

Where:

Absorbed Dose = Daily dose of DDT_{tot} averaged over a lifetime, in mg/kg-day. Also known as "Lifetime Average Daily Dose."
CS = DDT_{tot} concentration in soil, in mg DDT_{tot}/kg soil
CF = Conversion factor = 1 0-6 kg/mg
SA = Surface area of skin exposed to soil = cm^2 skin/day
AF = Adherence factor of soil to skin = mg soil/cm^2 skin
ABS = Fraction of soil-borne DDT_{tot} absorbed systemically (unitless), i.e., percent absorbed/100.
FI = Fraction of soil per day coming from contaminated source (unitless).

Assumes skin contact occurs only while receptors are awake, and the residence is the only contaminated area of interest.

EF = Exposure frequency in days per year, i.e., "days/week x weeks/year."
ED = Exposure duration in years.
BW = Body weight in kilograms.
AT = Averaging time: period over which exposure is averaged, in days. For carcinogens, AT typically is a human lifetime in days, which is "365 days/year x 70 years."

Calculation of "Absorbed Dose" was broken up into several components, for simplifying exposure calculations, as follows:

1. First, the total period of exposure, in days, was calculated, as follows:

FI x EF x ED = Total Days Exposed

The "Total Days Exposed" was calculated for an adult living at a residence for a total of 30 years, and staying home daily as a homemaker or for employment in the home or on the residence property.

Where:
FI = hours exposed/hours awake per day
EF = days/week x weeks/year exposed
ED = duration of exposure period, in years.

Weekday Exposure:
FI = hours at home awake/total hours awake. Time awake is 16 hours/day, with all 16 hours/day spent at home. Therefore, FI = 16 hours home awake/16 hours awake.
EF = weekdays home/week x weeks home/year, i.e., 5 days/week x 49 weeks/year.
ED = 30 years.

The "Total Weekdays Exposed" is as follows:
16 hours/16 hours x 5 days/week x 49 weeks/year x 30 years = 7,350 Days

Weekend Exposure:
FI = hours at home awake/total hours awake. Time awake is 16 hours/day, with 4 hours/day spent away from home for shopping, errands, or recreation. Therefore, the time spent at home = 16-4 = 12 hours/day, and FI = 12 hours home awake/16 hours awake.
EF = weekend days home/week x weeks home/year, i.e., 2 days/week x 49 weeks/year.
ED = 30 years.

The "Total Weekend Days Exposed" is as follows:
12 hours/16 hours x 2 days/week x 49 weeks/year x 30 years = 2,205 Days

Total Days Exposed = Weekdays + Weekends
= 7,350 days + 2,205 days
= 9,555 days

2. "Total Soil Dose" is then calculated, as follows:

$$\text{Total Soil Dose} = \frac{\text{Total Days Exposed x SA x AF}}{\text{BW}}$$

Where:
Total Days Exposed = 9,555 days
SA = 2290 cm^2 soil/day
AF = 0.5 mg soil/cm^2 skin
BW = 70 kg

$$\text{Total Soil Dose} = \frac{\text{9,555 days x 2290 cm}^2\text{ skin/day x 0.5 mg soil/cm}^2\text{ skin}}{\text{70 kg}}$$

= 156,293 mg soil/kg body weight

3. This dose of soil averaged over a lifetime ("Lifetime Average Daily Dose of Soil;" $LADD_{soil}$) is calculated as follows:

$$LADD_{soil} = \frac{\text{Total Soil Dose}}{\text{AT}}$$

Where:
Total Soil Dose = 156,293 mg soil/kg body weight
AT = 365 days/year x 70 years

$$LADD_{soil} = \frac{\text{156,293 mg soil/kg body weight}}{\text{365 days/year x 70 years}}$$

= 6.117 mg soil/kg body weight-day

4. The absorbed dose of DDT_{tot} averaged over a lifetime ("Lifetime Average Daily Dose of DDT_{tot}; $LADD_{DDT}$) is as follows:

$$LADD_{DDT} = LADD_{soil} \text{ x CS x CF x ABS}$$

Where:

$LADD_{soil}$ = 6.117 mg soil/kg body weight
CS = 1 mg DDT_{tot}/kg soil
CF = 10-6 kg/mg
ABS = 0.05

$LADD_{DDT}$ = 6.117 mg soil/kg-day x 1 mg DDT_{tot}/kg soil x 10-6 kg/mg x 0.05

= 0.306x10-6 mg DDT_{tot}/kg-day

= 3.06x10-7 mg DDT_{tot}/kg-day

Note, in this example, that $LADD_{DDT}$ is equivalent to "Absorbed Dose" in the USEPA equation above.

APPENDIX 7

RESIDENTIAL DERMAL SOIL EXPOSURE
ADULT FOR 30 YEARS
HOMEMAKER OR EMPLOYED AT HOME
A "HIGH EXPOSURE LEVEL" SCENARIO

1 ASSUMPTIONS

DIFFERENCE FROM "TYPICAL" CASE - Forearms and lower legs were exposed, in addition to head and hands.

1.1 Adults live at residence for 30 years.

1.2 Time spent at residence:

1.2.1 Weekdays: At home 24 hours/day, 5 days/week, for 49 weeks/year.

1.2.2 Weekends: At home 20 hours/day, 2 days/week, for 49 wee ks/year.

1.2.3 Vacations: Away from home 24 hours/day for 3 weeks/year.

1.3 Body parts exposed to soil are head, forearms, hands, and lower legs for males, with surface area of 6150 cm^2 (USEPA, 1989b, Page 4-11). No information was given for adult females.

1.4 Factor for adherence of soil to skin = 0.5 mg soil/cm^2 (see Sedman, 1989, for discussion).

1.5 Fraction of soil-borne DDT_{tot} which is absorbed systemically through the skin in 24 hours (dermal absorption) is 0.05, i.e., 5 percent. Five percent dermal absorption of soil-borne DDT_{tot} is based on the data of Wester et al (1990).

1.6 Body weight value of adult is 70 kg (USEPA, 1989a, Page 6-40).

1.7 Concentration of DDT_{tot} in soil = 1 ppm = 1 mg DDT_{tot}/kg soil.

1.8 Exposure to contaminated soil occur s only while adults are awake and at home.

2 CALCULATIONS

Calculations were based on the following equation adapted from USEPA (USEPA, 1989a, Page 6-41):

$$\text{Absorbed Dose} = \frac{CS \times CF \times SA \times AF \times ABS \times FI \times EF \times ED}{BW \times AT}$$

Where:

Absorbed Dose = Daily dose of DDT_{tot} averaged over a lifetime, in mg/kg-day. Also known as "Lifetime Average Daily Dose."

CS = DDT_{tot} concentration in soil, in mg DDT_{tot}/kg soil

CF = Conversion factor = 10-6 kg/mg

SA = Surface area of skin exposed to soil = cm^2 skin/day

AF = Adherence factor of soil to skin = mg soil/cm^2 skin

ABS = Fraction of soil-borne DDT_{tot} absorbed systemically (unitless), i.e., percent absorbed/100.
FI = Fraction of soil per day coming from contaminated source (unitless). Assumes skin contact occurs only while receptors are awake, and the residence is the only contaminated area of interest.
EF = Exposure frequency in days per year, i.e., "days/week x weeks/year."
ED = Exposure duration in years.
BW = Body weight in kilograms.
AT = Averaging time: period over which exposure is averaged, in days. For carcinogens, AT typically is a human lifetime in days, which is "365 days/year x 70 years."

Calculation of "Absorbed Dose" was broken up into several components, for simplifying exposure calculations, as follows:

1. First, the total period of exposure, in days, was calculated, as follows:

FI x EF x ED = Total Days Exposed

The "Total Days Exposed" was calculated for an adult living at a residence for a total of 30 years, and staying home daily as a homemaker or for employment in the home on the residence property.

Where:
FI = hours exposed/hours awake per day
EF = days/week x weeks/year exposed
ED = duration of exposure period, in years.

Weekday Exposure:
FI = hours at home awake/total hours awake. Time awake is 16 hours/day, with all 16 hours/day spent at home. Therefore, FI = 16 hours home awake/16 hours awake.
EF = weekdays home/week x weeks home/year, i.e., 5 days/week x 49 weeks/year.
ED = 30 years.

The "Total Weekdays Exposed" is as follows:

16 hours/16 hours x 5 days/week x 49 weeks/year x 30 years = 7,350 Days

Weekend Exposure:
FI = hours at home awake/total hours awake. Time awake is 16 hours/day, with 4 hours/day spent away from home for shopping, errands, or recreation. Therefore, the time spent at home = 16-4 = 12 hours/day, and FI = 12 hours home awake/16 hours awake.
EF = weekend days home/week x weeks home/year, i.e., 2 days/week x 49

weeks/year.
ED = 30 years.

The "Total Weekend Days Exposed" is as follows:
12 hours/16 hours x 2 days/week x 49 weeks/year x 30 years = 2,205 Days

Total Days Exposed = Weekdays + Weekends
= 7,350 days + 2,205 days
= 9,555 days

2. "Total Soil Dose" is then calculated, as follows:

$$\text{Total Soil Dose} = \frac{\text{Total Days Exposed x SA x AF}}{\text{BW}}$$

Where:
Total Days Exposed = 9,555 days
SA = 6150 cm^2 soil/day
AF = 0.5 mg soil/cm^2 skin
BW = 70 kg

$$\text{Total Soil Dose} = \frac{9{,}555 \text{ days x } 6150 \text{ cm}^2 \text{ skin/day x } 0.5 \text{ mg soil/cm}^2 \text{ skin}}{70 \text{ kg}}$$

= 419,738 mg soil/kg body weight

3. This dose of soil averaged over a lifetime ("Lifetime Average Daily Dose of Soil;" $LADD_{soil}$) is calculated as follows:

$$LADD_{soil} = \frac{\text{Total Soil Dose}}{\text{AT}}$$

Where:
Total Soil Dose = 419,738 mg so il/kg body weight
AT = 365 days/year x 70 years

$$LADD_{soil} = \frac{419{,}738 \text{ mg soil/kg body weight}}{365 \text{ days/year x } 70 \text{ years}}$$

= 16.428 mg soil/kg body weight-day

4. The absorbed dose of DDT_{tot} averaged over a lifetime ("Lifetime Average Daily Dose of DDT_{tot}; $LADD_{DDT}$) is as follows:

$$LADD_{DDT} = LADD_{soil} \text{ x CS x CF x ABS}$$

Where:

LADDsoil = 16.428 mg soil/kg body weight
CS = 1 mg DDT_{tot}/kg soil
CF = 10-6 kg/mg
ABS = 0.05

$$LADD_{DDT} = 16.428 \text{ mg soil/kg-day x 1 mg } DDT_{tot}\text{/kg soil x 10-6 kg/mg x 0.05}$$

$$= 0.821\text{x10-6 mg } DDT_{tot}\text{/kg-day}$$

$$= 8.21\text{x10-7 mg } DDT_{tot}\text{/kg-day}$$

Note, in this example, that $LADD_{DDT}$ is equivalent to "Absorbed Dose" in the USEPA equation above.

APPENDIX 8

RESIDENTIAL SOIL INGESTION CHILDREN AGES 1 THROUGH 17

1 ASSUMPTIONS

1.1 Children live at residence (with parents) from birth to age 18, then leave. They stay at home for 24 hours per day each day during ages 1 through 5, and attend school away from home for 8 hours per day during ages 6 through 17.

1.2 Time spent at residence:

1.2.1 Ages 1 through 5:
Home for 24 hours per day continuously, except during a 3 week holiday and vacation period during which they accompany parents in travel away from home.

1.2.2 Ages 6 through 17:
Schoolyear weekdays: At school 8 hours per day, 5 days per week, for 36 weeks per year, and at home 16 hours per day, 5 days per week for 36 weeks per year.
Schoolyear weekends: At home 21 to 24 hours per day (age-dependent), 2 days per week, for 36 weeks per year.
Note: A school year of 36 weeks is based on California requirements that public schools must have classes for about 180 days per year (180 days -- 5 days/week = 36 weeks).
Vacation from school: At home 16 to 24 hours per day (age-dependent), 7 days per week, for 13 weeks/year.
Note: All age groups are away from home for 3 weeks per year for holidays and vacations.

1.3 Soil ingestion is 200 mg/day for ages 1 through 6, and 100 mg/day for ages 7 and older (USEPA, 1989a, Page 6-40 ; USEPA 1989b, Pages 2-40 to 2-59).

1.4 Fraction of ingested DDT_{tot} which is absorbed systemically is 1.0, i.e., 100 percent. One-hundred percent oral absorption of soil-borne DDT_{tot} is assumed, in the absence of experimental information obtained with soil as the medium of exposure.

1.5 Body weight values - means of fiftieth percentile values for males and females, combined (USEPA, 1989b, Pages 5-44 and 5-45):
Ages 1 through 5 = 15.0 kg
Age 6 = 21.5 kg
Ages 7 through 17 = 43.5 kg

1.6 Concentration of DDT_{tot} in soil = 1 ppm = 1 mg DDT_{tot}/kg soil.

1.7 Exposure to contaminated soil occurs only while children are awake and at home.

2 CALCULATIONS

Calculations were based on the following equation adapted from USEPA (USEPA, 1989a, Page 6-40):

$$\text{Intake} = \frac{CS \times CF \times IR \times ABS \times FI \times EF \times ED}{BW \times AT}$$

Where:

Intake = Daily dose of DDT_{tot} averaged over a lifetime, in mg/kg-day. Also known as "Lifetime Average Daily Dose."
CS = DDT_{tot} concentration in soil, in mg DDT_{tot}/kg soil.
CF = Conversion factor = 10-6 kg/mg.
IR = Soil ingestion rate, in mg soil/day.
ABS = Fraction of soil-borne DDT_{tot} absorbed systemically (unitless), i.e., percent absorbed.
FI = Fraction of soil per day coming from contaminated source (unitless). Assumes soil ingestion occurs only while receptors are awake.
EF = Exposure frequency in days per year, i.e., "days/week x weeks/year."
ED = Exposure duration in years.
BW = Body weight in kilograms.
AT = Averaging time: period over which exposure is averaged, in days. For carcinogens, AT typically is a human lifetime in days, which is "365 days/year x 70 years."

Calculation of "Intake" was broken up into several components, for simplifying exposure calculations, as follows:

1. First, the total period of exposure, in days, was calculated, as follows:

$$FI \times EF \times ED = \text{Total Days Exposed}$$

Where:

FI = hours exposed/hours awake per day.
EF = days/week x weeks/year exposed.
ED = duration of exposure period, in years.

The "Total Days Exposed" was calculated for each age group, according to weekday or weekend activities. The Age 6 group was treated separately, because six year old children are assumed to go to school, but the default value for soil ingestion included children of age six and younger. A different default value is used for children of age 7 and older. Therefore, for the purposes of this example, the six year old group was not included with either the 1 through 5 year old children or those of age 7 through 17, but was treated separately.

Ages 1 through 5

FI x EF x ED = Total Days Exposed: Ages 1 Through 5

Where:

FI = hours awake at home/total hours awake per day. Time awake is assumed to average 12 hours/day for this age group, all of which is spent at home. Therefore, FI = 12 hours home/12 hours awake.

EF = days at home/week x weeks at home/year. Assume child is home for entire day, 7 days/week for 49 weeks/year.

ED = 5 years (age 1 through 5).

The "Total Days Exposed" is as follows:
12 hours/12 hours x 7 days/week x 49 w eeks/year x 5 years = 1,715 Days

Age 6

FI x EF x ED = Total Days Exposed: Age 6

Weekdays Exposed During Schoolyear, Where:

FI = hours awake at home/total hours awake per day. Time awake is assumed to average 13 hours/day for this age group, with 8 hours/day spent at school. Therefore, hours awake at home = 13-8 = 5 hours, and FI = 5 hours awake at home/13 hours awake.

EF = days at home/week x weeks at home/year. Assume child is home for 5 weekdays/week, 36 weeks/year.

ED = 1 year (age 6 only).

The "Total Weekdays Exposed" is as follows:
5 hours/13 hours x 5 days/week x 36 weeks/year x 1 year = 69.2 Days

Weekends Exposed During Schoolyear, Where:

FI = hours awake at home/total hours awake per day. Time awake is assumed to average 13 hours/day for this age group, all of which is spent at home. Therefore, FI = 13 hours home/13 hours awake.

EF = days at home/week x weeks at home/year. Assume child is home for 2 weekend days/week for 36 weeks/year.

ED = 1 year (age 6 only).

The "Total Weekend Days Exposed" is as follows:
13 hours/13 hours x 2 days/week x 36 weeks/year x 1 years = 72.0 Days

Vacation From School Exposure, Where:

FI = hours awake at home/total hours awake per day. Time awake is assumed to average 13 hours/day for this age group, 11 hours of which is spent at home (with 2 hours/day spent at a park or friend's residence). Therefore, FI = 11 hours at home/13 hours awake.

EF = days at home/week x weeks at home/year. Assume child is home for all 7 days/week during school vacation for 13 weeks/year.

ED = 1 year (age 6 only).

The "Total Vacation Days Exposed" is as follows:
11 hours/13 hours x 7 days/week x 13 weeks/year x 1 year = 77.0 Days

Total Days Exposed = Weekdays + Weekends + School Vacation

= 69.2 days + 72.0 days + 77.0 days

= 218.2 days

Ages 7 Through 17

FI x EF x ED = Total Days Exposed: Ages 7 Through 17

Weekdays Exposed During Schoolyear, Where:

FI = hours awake at home/total hours awake per day. Time awake is assumed to average 16 hours/day for this age group, with 8 hours/day spent at school. Therefore, hours awake at home = 16-8 = 8 hours, and FI = 8 hours awake at home/16 hours awake.

EF = days at home/week x weeks at home/year. Assume child is home for 5 weekdays/week, 36 weeks/year.

ED = 11 years (age 7 through 17).

The "Total Weekdays Exposed" is as foll ows:
8 hours/16 hours x 5 days/week x 36 weeks/year x 11 years = 990.0 Days

Weekends Exposed During Schoolyear, Where:

FI = hours awake at home/total hours awake per day. Time awake is assumed to average 16 hours/day for this age group, 13 hours of which is spent at home (with 3 hours/day spent at a park or friend's residence). Therefore, FI = 13 hours home/16 hours awake.

EF = days at home/week x weeks at home/year. Assume child is home for 2 weekend days/week for 36 weeks/year.

ED = 11 years (age 7 through 17).

The "Total Weekend Days Exposed" is as follows:

13 hours/16 hours x 2 days/week x 36 weeks/year x 11 years = 643.5 Days

Vacation From School Exposure, Where:

FI = hours awake at home/total hours awake per day. Time awake is assumed to average 16 hours/day for this age group, with 8 hours/day spent at home (and 8 hours/day at the park, beach, or friend's residence). Therefore, FI = 8 hours at home/16 hours awake.

EF = days at home/week x weeks at home/year. Assume child is home for all 7 days/week during school vacation for 13 weeks/year.

ED = 11 years (age 7 through 17).

The "Total Vacation Days Exposed" is as follows:

8 hours/16 hours x 7 days/week x 13 weeks/year x 11 years = 500.5 Days

Total Days Exposed = Weekdays + Weekends + School Vacation

= 990.0 days + 643.5 days + 500.5 days

= 2,134.0 days

2. "Total Soil Dose" is then calculated, as follow s:

$$\text{Total Soil Dose} = \frac{\text{Total Days Exposed x IR}}{\text{BW}}$$

Where:

IR = 200 mg/day for ages 1 through 6, and 100 mg/day for ages 7 and older.

BW = 15.0 kg for ages 1 through 5, 21.5 kg for age 6, and 43.5 kg for ages 7 through 17.

Ages 1 Through 5

$$\text{Total Soil Dose} = \frac{\text{1,715 days x 200 mg soil/day}}{\text{15.0 kg}}$$

= 22,866.7 mg soil/kg body weight

Age 6

$$\text{Total Soil Dose} = \frac{218.2 \text{ days x } 200 \text{ mg soil/day}}{21.5 \text{ kg}}$$

$$= 2{,}029.8 \text{ mg soil/kg body weight}$$

Ages 7 Through 17

$$\text{Total Soil Dose} = \frac{2{,}134.0 \text{ days x } 100 \text{ mg soil/day}}{43.5 \text{ kg}}$$

$$= 4{,}905.7 \text{ mg soil/kg body weight}$$

Total Soil Dose: Ages 1 Through 17
= (22,866.7 + 2,029.8 + 4,905.7) mg soil/kg body weight
= 29,802 mg soil/kg body weight

3. This dose of soil averaged over a lifetime ("Lifetime Average Daily Dose of Soil;" LADDsoil) is calculated as follows:

$$\text{LADDsoil} = \frac{\text{Total Soil Dose}}{\text{AT}}$$

Where:
Total Soil Dose = 29,802 mg soil/kg body weight
AT = 365 days/year x 70 years

$$\text{LADDsoil} = \frac{29{,}802 \text{ mg soil/kg body weight}}{365 \text{ days/year x } 70 \text{ years}}$$

$$= 1.166 \text{ mg soil/kg body weight-day}$$

4. The absorbed dose of DDT_{tot} averaged over a lifetime ("Lifetime Average Daily Dose of DDT_{tot}; $LADD_{DDT}$) is as follows:

$$LADD_{DDT} = \text{LADDsoil x CS x CF x ABS}$$

Where:

$LADD_{soil}$ = 1.166 mg soil/kg body weight
CS = 1 mg DDT_{tot}/kg soil
CF = 10-6 kg/mg
ABS = 1.0

$LADD_{DDT}$ = 1.166 mg soil/kg-day x 1 mg DDT_{tot}/kg soil x 10-6 kg/mg x 1.0

= 1.17x10-6 mg DDT_{tot}/kg-day

Note, in this example, that $LADD_{DDT}$ is equivalent to "Intake" in the equation adapted from USEPA.

APPENDIX 9

RESIDENTIAL DERMAL SOIL EXPOSURE CHILDREN AGES 1 THROUGH 17 A "TYPICAL" EXPOSURE SCENARIO

1 ASSUMPTIONS

1.1 Children live at the residence (with parents) from birth to age 18, the n leave. They stay at home for 24 hours per day each day during ages 1 through 5, and attend school away from home for 8 hours per day during ages 6 through 17.

1.2 Time spent at residence:

1.2.1 Ages 1 through 5:

Home for 24 hours per day continuously, except during a 3 week holiday and vacation period during which they accompany parents in travel away from home.

1.2.2 Ages 6 through 17:

Schoolyear weekdays: At school 8 hours per day, 5 days per week, for 36 weeks per year, and at home 16 hours per day, 5 days per week for 36 weeks per year.

Schoolyear weekends: At home 21 to 24 hours per day (age-dependent), 2 days per week, for 36 weeks per year.

Note: A school year of 36 weeks is based on California requirements that public schools must have classes for about 180 days per year (180 days -- 5 days/week = 36 weeks).

Vacation from school: At home 16 to 24 hours per day (age-dependent), 7 days per week, for 13 weeks.

Note: All age groups are away from home for 3 weeks per year for holidays and vacations.

1.3 Body parts and surface area of skin exposed to soil - head and hands, based on best estimate of data from USEPA (USEPA, 1989b, Pages 4-12 and 13, and 4-30 and 31):

Ages 1 -> 5 = 1400 cm^2
Age 6 = 1520 cm^2
Ages 7 -> 17 = 2050 cm^2

1.4 Factor for adherence of soil to skin = 0.5 mg soil/cm^2 (see Sedman, 1989, for discussion).

1.5 Fraction of soil-borne DDT_{tot} which is absorbed systemically through the skin in 24 hours (dermal absorption) is 0.05, i.e., 5 percent. Five percent dermal absorption of soil-borne DDT_{tot} is based on the data of Wester et al (1990).

1.6 Body weight values - means of fiftieth percentile values for males and females, combined (USEPA, 1989b, Pages 5-44 and 5-45):

Ages 1 through 5 = 15.0 kg
Age 6 = 21.5 kg

Ages 7 through 17 = 43.5 kg

1.7 Concentration of DDT_{tot} in soil = 1 ppm = 1 mg DDT_{tot}/kg soil.

1.8 Exposure to contaminated soil occurs only while children are awake and at home.

2 CALCULATIONS

Calculations were based on the following equation adapted from USEPA (USEPA, 1989a, Page 6-41):

$$\text{Absorbed Dose} = \frac{CS \times CF \times SA \times AF \times ABS \times FI \times EF \times ED}{BW \times AT}$$

Where:

Absorbed Dose = Daily dose of DDT_{tot} averaged over a lifetime, in mg/kg-day. Also known as "Lifetime Average Daily Dose."
CS = DDT_{tot} concentration in soil, in mg DDT_{tot}/kg soil
CF = Conversion factor = 10-6 kg/mg
SA = Surface area of skin exposed to soil = cm ^{2} skin/day
AF = Adherence factor of soil to skin = mg soil/cm ^{2} skin
ABS = Fraction of soil-borne DDT_{tot} absorbed systemically (unitless), i.e., percent absorbed/100.
FI = Fraction of soil per day coming from contaminated source (unitless). Assumes skin contact occurs only while receptors are awake, and the park is the only contaminated area of interest.
EF = Exposure frequency in days per year, i.e., "days/week x weeks/year."
ED = Exposure duration in years.
BW = Body weight in kilograms.
AT = Averaging time: period over which exposure is averaged, in days. For carcinogens, AT typically is a human lifetime in days, which is "365 days/year x 70 years."

Calculation of "Absorbed Dose" was broken up into several components, for simplifying exposure calculations, as follows:

1. First, the total period of exposure, in days, was calculated, as follows:

$$FI \times EF \times ED = \text{Total Days Exposed}$$

Where:

FI = hours exposed/hours awake per day
EF = days/week x weeks/year exposed
ED = duration of exposure period, in years.

The "Total Days Exposed" was calculated for three age groups, 1 through 5 years, 6 years, and 7 through 17 years, according to weekday or weekend activities. The Age 6 group wastreated separately, as follows: six year old children are assumed to go to school along with the older children, but the default value for soil ingestion used in the other Appendices for 6 year old children was identical to that for younger children and different from that for children of age 7 and older. Therefore, to be consistent with the soil ingestion scenarios in the other Appendices, the six year old group was not included with either the 1 through 5 year old children or those of age 7 through 17, but was treated separately.

Ages 1 through 5

FI x EF x ED = Total Days Exposed: Ages 1 Through 5

Where:

FI = hours awake at home/total hours awake per day. Time awake is assumed to average 12 hours/day for this age group, all of which is spent at home. Therefore, FI = 12 hours home/12 hours awake.

EF = days at home/week x weeks at home/year. Assume child is home for entire day, 7 days/week for 49 weeks/year.

ED = 5 years (age 1 through 5).

The "Total Days Exposed" is as follows:
12 hours/12 hours x 7 days/week x 49 weeks/year x 5 years = 1,715 Days

Age 6

FI x EF x ED = Total Days Exposed: Age 6

Weekdays Exposed During Schoolyear, Where:

FI = hours awake at home/total hours awake per day. Time awake is assumed to average 13 hours/day for this age group, with 8 hours/day spent at school. Therefore, hours awake at home = 13-8 = 5 hours, and FI = 5 hours awake at home/13 hours awake.

EF = days at home/week x weeks at home/year. Assume child is home for 5 weekdays/week, 36 weeks/year.

ED = 1 year (age 6 only).

The "Total Weekdays Exposed" is as follows:
5 hours/13 hours x 5 days/week x 36 weeks/year x 1 year = 69.2 Da ys

Weekends Exposed During Schoolyear, Where:

FI = hours awake at home/total hours awake per day. Time awake is assumed to average 13 hours/day for this age group, all of which is spent at home. Therefore, FI = 13 hours home/13 hours awake.

EF = days at home/week x weeks at home/year. Assume child is home for 2 weekend days/week for 36 weeks/year.
ED = 1 year (age 6 only).

The "Total Weekend Days Exposed" is as follows:
13 hours/13 hours x 2 days/week x 36 weeks/year x 1 years = 72.0 Days

Vacation From School Exposure, Where:
FI = hours awake at home/total hours awake per day. Time awake is assumed to average 13 hours/day for this age group, 11 hours of which is spent at home (with 2 hours/day spent at a park or friend's residence). Therefore, FI = 11 hours at home/13 hours awake.
EF = days at home/week x weeks at home/year. Assume child is home for all 7 days/week during school vacation for 13 weeks/year.
ED = 1 year (age 6 only).

The "Total Vacation Days Exposed" is as follows:
11 hours/13 hours x 7 days/week x 13 weeks/year x 1 year = 77.0 Days

Total Days Exposed = Weekdays + Weekends + School Vacation

= 69.2 days + 72.0 days + 77.0 days

= 218.2 days

Ages 7 Through 17

FI x EF x ED = Total Days Exposed: Ages 7 Through 17

Weekdays Exposed During Schoolyear, Where:
FI = hours awake at home/total hours awake per day. Time awake is assumed to average 16 hours/day for this age group, with 8 hours/day spent at school. Therefore, hours awake at home = 16-8 = 8 hours, and FI = 8 hours awake at home/16 hours awake.
EF = days at home/week x weeks at home/year. Assume child is home for 5 weekdays/week, 36 weeks/year.
ED = 11 years (age 7 through 17).

The "Total Weekdays Exposed" is as follows:
8 hours/16 hours x 5 days/week x 36 weeks/year x 11 years = 990.0 Days

Weekends Exposed During Schoolyear, Where:
FI = hours awake at home/total hours awake per day. Time awake is assumed to average 16 hours/day for this age group, 13 hours of which is spent at home (with 3 hours/day spent at a park or friend's residence). Therefore, FI = 13 hours home/16 hours awake.

EF = days at home/week x weeks at home/year. Assume child is home for 2 weekend days/week for 36 weeks/year.
ED = 11 years (age 7 through 17).

The "Total Weekend Days Exposed" is as follows:
13 hours/16 hours x 2 days/week x 36 weeks/year x 11 years = 643.5 Days

Vacation From School Exposure, Where:

FI = hours awake at home/total hours awake per day. Time awake is assumed to average 16 hours/day for this age group, with 8 hours/day spent at home (and 8 hours/day at the park, beach, or friend's residence). Therefore, FI = 8 hours at home/16 hours awake.
EF = days at home/week x weeks at home/year. Assume child is home for all 7 days/week during school vacation for 13 weeks/year.
ED = 11 years (age 7 through 17).

The "Total Vacation Days Exposed" is as follows:
8 hours/16 hours x 7 days/week x 13 weeks/year x 11 years = 500.5 Days

Total Days Exposed = Weekdays + Weekends + School Vacation

= 990.0 days + 643.5 days + 500.5 days

= 2,134.0 days

2. "Total Soil Dose" is then calculated, as follows:

$$\text{Total Soil Dose} = \frac{\text{Total Days Exposed x SA x AF}}{\text{BW}}$$

Where:

SA = 1400 cm^2/day for ages 1 through 5
= 1520 cm^2/day for age 6
= 2050 cm^2/day for ages 7 through 17
AF = 0.5 mg soil/cm^2 skin
BW = 15.0 kg for ages 1 through 5, 21.5 kg for age 6, and 43.5 kg for ages 7 through 17.

Ages 1 Through 5

$$\text{Total Soil Dose} = \frac{1{,}715 \text{ days x } 1400 \text{ cm}^2/\text{day x } 0.5 \text{ mg soil/cm}^2 \text{ skin}}{15.0 \text{ kg}}$$

= 80,033 mg soil/kg body weight

Age 6

$$\text{Total Soil Dose} = \frac{218.2 \text{ days x } 1520 \text{ cm}^2/\text{day x } 0.5 \text{ mg soil/cm}^2 \text{ skin}}{21.5 \text{ kg}}$$

= 7,713.1 mg soil/kg body weight

Ages 7 Through 17

$$\text{Total Soil Dose} = \frac{2{,}134.0 \text{ days x } 2050 \text{ cm}^2/\text{day x } 0.5 \text{ mg soil/cm}^2 \text{ skin}}{43.5 \text{ kg}}$$

= 50,283.9 mg soil/kg body weight

Total Soil Dose: Ages 1 Through 17
= (80,033 + 7,713.1 + 50.283.9) mg soil/kg
= 138,030 mg soil/kg body weight

3. This dose of soil averaged over a lifetime ("Lifetime Average Daily Dose of Soil;" $LADD_{soil}$) is calculated as follows:

$$LADD_{soil} = \frac{\text{Total Soil Dose}}{AT}$$

Where:
Total Soil Dose = 138,030 mg soil/kg body weight
AT = 365 days/year x 70 years

$$LADD_{soil} = \frac{138{,}030 \text{ mg soil/kg body weight}}{365 \text{ days/year x } 70 \text{ years}}$$

$$= 5.402 \text{ mg soil/kg body weight-day}$$

4. The absorbed dose of DDT_{tot} averaged over a lifetime ("Lifetime Average Daily Dose of DDT_{tot}; $LADD_{DDT}$) is as follows:

$$LADD_{DDT} = LADD_{soil} \text{ x CS x CF x ABS}$$

Where:

$LADD_{soil}$ = 5.402 mg soil/kg-day
CS = 1 mg DDT_{tot}/kg soil
CF = 10-6 kg/mg
ABS = 0.05

$$LADD_{DDT} = 5.402 \text{ mg soil/kg-day x 1 mg } DDT_{tot}\text{/kg soil x 10-6 kg/mg x } 0.05$$

$$= 0.270\text{x}10\text{-}6 \text{ mg } DDT_{tot}\text{/kg-day}$$

$$= 2.70\text{x}10\text{-}7 \text{ mg } DDT_{tot}\text{/kg-day}$$

Note, in this example, that $LADD_{DDT}$ is equivalent to "Absorbed Dose" in the USEPA equation above.

APPENDIX 10

RESIDENTIAL DERMAL SOIL EXPOSURE
CHILDREN AGES 1 THROUGH 17
A "HIGH" EXPOSURE SCENARIO, NUMBER ONE

1 ASSUMPTIONS

DIFFERENCE FROM "TYPICAL" CASE - Arms and legs were exposed on weekends and school vacations, in addition to head and hands, in children of age 6 and older.

1.1 Children live at residence from birth to age 18, then leave. They stay at home for 24 hours per day each day during ages 1 through 5, and attend school away from home for 8 hours per day during ages 6 through 17.

1.2 Time spent at residence:

1.2.1 Ages 1 through 5:

Home for 24 hours/day continuously, except during a 3 week holiday and vacation period during which they accompany parents in travel away from home.

1.2.2 Ages 6 through 17:

Schoolyear weekdays: At school 8 hours/day, 5 days/week, for 36 weeks/year, and at home 16 hours per day, 5 days per week for 36 weeks/year.

Schoolyear weekends: At home, 21 to 24 hours/day (age-dependent), 2 days/week, for 36 weeks/year.

Note: A school year of 36 weeks is based on California requirements that public schools must have classes for about 180 days per year (180 days -- 5 days/week = 36 weeks).

Vacation from school: At home 16 to 24 hours/day (age dependent), 7 days/week, for 13 weeks/year.

Note: All age groups are away from home for 3 weeks per year for holidays and vacations.

1.3 Body parts and surface area of skin exposed to soil, based on best estimate of data from USEPA (USEPA, 1989b, Pages 4-12 and 13, and 4-30 and 31):

Ages 1 -> 5	= 1400 cm^2	head and hands, everyday.
Age 6	= 1520 cm^2	head and hands, weekdays in school year.
	= 4970 cm^2	head, hands, arms, and legs, weekends in school year, and school vacations.
Ages 7 -> 17	= 2050 cm^2	head and hands, weekdays in school year
	= 8010 cm^2	head, hands, arms, and legs, weekends in school year, and school vacations.

1.4 Factor for adherence of soil to skin = 0.5 mg soil/cm^2 (see Sedman, 1989, for discussion).

1.5 Fraction of soil-borne DDT_{tot} which is absorbed systemically through the skin in 24 hours (dermal absorption) is 0.05, i.e., 5 percent. Five percent dermal absorption of soil-borne DDT_{tot} is based on the data of Wester et al (1990).

1.6 Body weight values = means of fiftieth percentile values for males and females, combined:

Ages 1 through 5 = 15.0 kg
Age 6 = 21.5 kg
Ages 7 through 17 = 43.5 kg

1.7 Concentration of DDT_{tot} in soil = 1 ppm = 1 mg DDT_{tot}/kg soil.

1.8 Exposure to contaminated soil occurs only while children are awake and at home.

2 CALCULATIONS

Calculations were based on the following equation adapted from USEPA (USEPA, 1989a, Page 6-41):

$$\text{Absorbed Dose} = \frac{CS \times CF \times SA \times AF \times ABS \times FI \times EF \times ED}{BW \times AT}$$

Where:

Absorbed Dose = Daily dose of DDT_{tot} averaged over a lifetime, in mg/kg-day. Also known as "Lifetime Average Daily Dose."
CS = DDT_{tot} concentration in soil, in mg DDT_{tot}/kg soil
CF = Conversion factor = 10-6 kg/mg
SA = Surface area of skin exposed to soil = cm^2 skin/day
AF = Adherence factor of soil to skin = mg soil/cm^2 skin
ABS = Fraction of soil-borne DDT_{tot} absorbed systemically (unitless), i.e., percent absorbed/100.
FI = Fraction of soil per day coming from contaminated source (unitless). Assumes skin contact occurs only while receptors are awake, and the park is the only contaminated area of interest.
EF = Exposure frequency in days per year, i.e., "days/week x weeks/year."
ED = Exposure duration in years.
BW = Body weight in kilogram s.
AT = Averaging time: period over which exposure is averaged, in days. For carcinogens, AT typically is a human lifetime in days, which is "365 days/year x 70 years."

Calculation of "Absorbed Dose" was broken up into several components, for simplifying exposure calculations, as follows:

1. First, the total period of exposure, in days, was calculated, as follows:

FI x EF x ED = Total Days Exposed

Where:

FI = hours exposed/hours awake per day
EF = days/week x weeks/year exposed
ED = duration of exposure period, in years.

The "Total Days Exposed" was calculated for three age groups, 1 through 5 years, 6 years, and 7 through 17 years, according to weekday or weekend activities. The Age 6 group was treated separately, as follows: six year old children are assumed to go to school along with the older children, but the default value for soil ingestion used in the other Appendices for 6 year old children was identical to that for younger children and different from that for children of age 7 and older. Therefore, to be consistent with the soil ingestion scenarios in the other Appendices, the six year old group was not included with either the 1 through 5 year old children or those of age 7 through 17, but was treated separately.

Ages 1 through 5

FI x EF x ED = Total Days Exposed: Ages 1 Through 5

Where:

FI = hours awake at home/total hours awake per day. Time awake is assumed to average 12 hours/day for this age group, all of which is spent at home. Therefore, FI = 12 hours home/12 hours awake.
EF = days at home/week x weeks at home/year. Assume child is home for entire day, 7 days/week for 49 weeks/year.
ED = 5 years (age 1 through 5).

The "Total Days Exposed" is as follo ws:
12 hours/12 hours x 7 days/week x 49 weeks/year x 5 years = 1,715 Days

Age 6

FI x EF x ED = Total Days Exposed: Age 6

Weekdays Exposed During Schoolyear, Where:

FI = hours awake at home/total hours awake per day. Time awake is assumed to average 13 hours/day for this age group, with 8 hours/day spent at school. Therefore, hours awake at home = 13-8 = 5 hours, and FI = 5 hours awake at home/13 hours awake.
EF = days at home/week x weeks at home/year. Assume child is home for 5 weekdays/week, 36 weeks/year.
ED = 1 year (age 6 only).

The "Total Weekdays Exposed" is as follows:
5 hours/13 hours x 5 days/week x 36 weeks/year x 1 year = 69.2 Days

Weekends Exposed During Schoolyear, Where:

FI = hours awake at home/total hours awake per day. Time awake is assumed to average 13 hours/day for this age group, all of which is spent at home. Therefore, FI = 13 hours home/13 hours awake.

EF = days at home/week x weeks at home/year. Assume child is home for 2 weekend days/week for 36 weeks/year.

ED = 1 year (age 6 only).

The "Total Weekend Days Exposed" is as follows:
13 hours/13 hours x 2 days/week x 36 weeks/year x 1 years = 72.0 Days

Vacation From School Exposure, Where:

FI = hours awake at home/total hours awake per day. Time awake is assumed to average 13 hours/day for this age group, 11 hours of which is spent at home (with 2 hours/day spent at a park or friend's residence). Therefore, FI = 11 hours at home/13 hours awake.

EF = days at home/week x weeks at home/year. Assume child is home for all 7 days/week during school vacation for 13 weeks/year.

ED = 1 year (age 6 only).

The "Total Vacation Days Exposed" is as follows:
11 hours/13 hours x 7 days/week x 13 weeks/year x 1 year = 77.0 Days

Total Days Exposed = Weekdays + Weekends + School Vacation

= 69.2 days + 72.0 days + 77.0 days

= 218.2 days

Ages 7 Through 17

FI x EF x ED = Total Days Exposed: Ages 7 Through 17

Weekdays Exposed During Schoolyear, Where:

FI = hours awake at home/total hours awake per day. Time awake is assumed to average 16 hours/day for this age group, with 8 hours/day spent at school. Therefore, hours awake at home = 16-8 = 8 hours, and FI = 8 hours awake at home/16 hours awake.

EF = days at home/week x weeks at home/year. Assume child is home for 5 weekdays/week, 36 weeks/year.

ED = 11 years (age 7 through 17).

The "Total Weekdays Exposed" is as follows:
8 hours/16 hours x 5 days/week x 36 weeks/year x 11 years = 990.0 Days

Weekends Exposed During Schoolyear, Where:

FI = hours awake at home/total hours awake per day. Time awake is assumed to average 16 hours/day for this age group, 13 hours of which is spent at home (with 3 hours/day spent at a park or friend's residence). Therefore, FI = 13 hours home/16 hours awake.

EF = days at home/week x weeks at home/year. Assume child is home for 2 weekend days/week for 36 weeks/year.

ED = 11 years (age 7 through 17).

The "Total Weekend Days Exposed" is as follows:
13 hours/16 hours x 2 days/week x 36 weeks/year x 11 years = 643.5 Days

Vacation From School Exposure, Where:

FI = hours awake at home/total hours awake per day. Time awake is assumed to average 16 hours/day for this age group, with 8 hours/day spent at home (and 8 hours/day at the park, beach, or friend's residence). Therefore, FI = 8 hours at home/16 hours awake.

EF = days at home/week x weeks at home/year. Assume child is home for all 7 days/week during school vacation for 13 weeks/year.

ED = 11 years (age 7 through 17).

The "Total Vacation Days Exposed" is as follows:
8 hours/16 hours x 7 days/week x 13 weeks/year x 11 years = 500.5 Days

Total Days Exposed = Weekdays + Weekends + School Vacation

= 990.0 days + 643.5 days + 500.5 days

= 2,134.0 days

2. "Total Soil Dose" is then calculated, as follows:

$$\text{Total Soil Dose} = \frac{\text{Total Days Exposed x SA x AF}}{\text{BW}}$$

Where:

SA = 1400 cm^2/day for ages 1 through 5 throughout year.
= 1520 cm^2/day for age 6, on weekdays during school year.
= 4970 cm^2/day for age 6, on weekends during school year, during school vacations.

= 2050 cm^2/day for ages 7 through 17, on weekdays during school year.
= 8010 cm^2/day for ages 7 through 17, on weekends during school year, and during school vacations.
AF = 0.5 mg soil/cm^2 skin
BW = 15.0 kg for ages 1 through 5, 21.5 kg for age 6, and 43.5 kg for ages 7 through 17.

Ages 1 Through 5

$$\text{Total Soil Dose} = \frac{1{,}715.0 \text{ days} \times 1400 \text{ cm}^2\text{/day} \times 0.5 \text{ mg soil/cm}^2 \text{ skin}}{15.0 \text{ kg}}$$

= 80,033 mg soil/kg body weight

Age 6

Weekdays During School Year

$$\text{Total Soil Dose} = \frac{69.2 \text{ days} \times 1520 \text{ cm}^2\text{/day} \times 0.5 \text{ mg soil/cm}^2 \text{ skin}}{21.5 \text{ kg}}$$

= 2,446.1 mg soil/kg body weight

Weekends During School Year

$$\text{Total Soil Dose} = \frac{72.0 \text{ days} \times 4970 \text{ cm}^2\text{/day} \times 0.5 \text{ mg soil/cm}^2 \text{ skin}}{21.5 \text{ kg}}$$

= 8321.9 mg soil/kg body weight

Vacation From School

$$\text{Total Soil Dose} = \frac{77.0 \text{ days} \times 4970 \text{ cm}^2\text{/day} \times 0.5 \text{ mg soil/cm}^2 \text{ skin}}{21.5 \text{ kg}}$$

= 8,899.8 mg soil/kg body weight

Total Soil Dose Age 6
= (2,446.1 + 8,321.9 + 8,899.8) mg soil/kg body weight
= 19,668 mg soil/kg body weight

Ages 7 Through 17

Weekdays During School Year

$$\text{Total Soil Dose} = \frac{990.0 \text{ days x } 2050 \text{ cm}^2\text{/day x } 0.5 \text{ mg soil/cm}^2 \text{ skin}}{43.5 \text{ kg}}$$

= 23,327.6 mg soil/kg body weight

Weekends During School Year

$$\text{Total Soil Dose} = \frac{643.5 \text{ days x } 8010 \text{ cm}^2\text{/day x } 0.5 \text{ mg soil/cm}^2 \text{ skin}}{43.5 \text{ kg}}$$

= 59,246.4 mg soil/kg body weight

Vacation From School

$$\text{Total Soil Dose} = \frac{500.5 \text{ days x } 8010 \text{ cm}^2\text{/day x } 0.5 \text{ mg soil/cm}^2 \text{ skin}}{43.5 \text{ kg}}$$

= 46,080.5 mg soil/kg body weight

Total Soil Dose Age 7 Through 17
= (23,327.6 + 59,246.4 + 46,080.5) mg soil/kg body weight
= 128,655 mg soil/kg body weight

Total Soil Dose Ages 1 Through 17
= (80,033 + 19,668 + 128,655) mg soil/kg
= 228,356 mg soil/kg body weight

3. This dose of soil averaged over a lifetime ("Lifetime Average Daily Dose of Soil;" $LADD_{soil}$) is calculated as follows:

$$LADD_{soil} = \frac{\text{Total Soil Dose}}{\text{AT}}$$

Where:

Total Soil Dose = 228,356 mg soil/kg body weight
AT = 365 days/year x 70 years

$$LADD_{soil} = \frac{228{,}356 \text{ mg soil/kg body weight}}{365 \text{ days/year x } 70 \text{ years}}$$

$$= 8.938 \text{ mg soil/kg body weight-day}$$

4. The absorbed dose of DDT_{tot} averaged over a lifetime ("Lifetime Average Daily Dose of DDT_{tot}; $LADD_{DDT}$) is as follows:

$$LADD_{DDT} = LADD_{soil} \text{ x CS x CF x ABS}$$

Where:

$LADD_{soil}$ = 8.938 mg soil/kg body weight-day
CS = 1 mg DDT_{tot}/kg soil
CF = 10-6 kg/mg
ABS = 0.05

$$LADD_{DDT} = 8.938 \text{ mg soil/kg-day x 1 mg } DDT_{tot}\text{/kg soil x 10-6 kg/mg x 0.05}$$

$$= 0.447\text{x10-6 mg } DDT_{tot}\text{/kg-day}$$

$$= 4.47\text{x10-7 mg } DDT_{tot}\text{/kg-day}$$

Note, in this example, that $LADD_{DDT}$ is equivalent to "Absorbed Dose" in the equation adapted from USEPA.

APPENDIX 11

RESIDENTIAL DERMAL SOIL EXPOSURE
CHILDREN AGES 1 THROUGH 17
A "HIGH" EXPOSURE SCENARIO, NUMBER TWO

1 ASSUMPTIONS

DIFFERENCE FROM "TYPICAL" CASE - Arms and legs were exposed, in addition to head and hands, in children of all ages.

1.1 Children live at residence from birth to age 18, then leave. They stay at home for 24 hours per day each day during ages 1 through 5, and attend school away from home for 8 hours per day during ages 6 through 17.

1.2 Time spent at residence:

1.2.1 Ages 1 through 5:

Home for 24 hours/day continuously, except during a 3 week holiday and vacation period during which they accompany parents in travel away from home.

1.2.2 Ages 6 through 17:

Schoolyear weekdays: At school 8 hours/day, 5 days/week, for 36 weeks/year, and at home 16 hours per day, 5 days per week for 36 weeks/year.

Schoolyear weekends: At home 21 to 24 hours/day (age-dependent), 2 days/week, for 36 weeks/year.

Note: A school year of 36 weeks is based on California requirements that public schools must have classes for about 180 days per year (180 days -- 5 days/week = 36 weeks).

Vacation from school: At home 16 to 24 hours/day (age-dependent), 7 days/week, for 13 weeks/year.

Note: All age groups are away from home for 3 weeks per year for holidays and vacations.

1.3 Area of skin exposed to soil, based on best estimate of data from USEPA (USEPA, 1989b, Pages 4-12 and 13, and 4-30 and 31), is head, hands, arms, and legs, as follows:

Ages 1 -> 5 = 4040 cm^2
Age 6 = 4970 cm^2
Ages 7 -> 17 = 8010 cm^2

1.4 Factor for adherence of soil to skin = 0.5 mg soil/cm^2 (see Sedman, 1989, for discussion).

1.5 Fraction of soil-borne DDT_{tot} which is absorbed systemically through the skin in 24 hours (dermal absorption) is 0.05, i.e., 5 percent. Five percent dermal absorption of soil-borne DDT_{tot} is based on the data of Wester et al (1990).

1.6 Body weight values = means of fiftieth percentile values for males and females, combined (USEPA, 1989b, Pages 5-44 and 5-45):

Ages 1 -> 5 = 15.0 kg
Age 6 = 21.5 kg
Ages 7 -> 17 = 43.5 kg

1.7 Concentration of DDT_{tot} in soil = 1 ppm = 1 mg DDT_{tot}/kg soil.

1.8 Exposure to contaminated soil occurs only while children are awake and at home.

2 CALCULATIONS

Calculations were based on the following equation adapted from USEPA (USEPA, 1989a, Page 6-41):

$$\text{Absorbed Dose} = \frac{CS \times CF \times SA \times AF \times ABS \times FI \times EF \times ED}{BW \times AT}$$

Where:

Absorbed Dose = Daily dose of DDT_{tot} averaged over a lifetime, in mg/kg-day. Also known as "Lifetime Average Daily Dose."
CS = DDT_{tot} concentration in soil, in mg DDT_{tot}/kg soil
CF = Conversion factor = 10-6 kg/mg
SA = Surface area of skin exposed to soil = cm ^{2} skin/day
AF = Adherence factor of soil to skin = mg soil/cm ^{2} skin
ABS = Fraction of soil-borne DDT_{tot} absorbed systemically (unitless), i.e., percent absorbed/100.
FI = Fraction of soil per day coming from contaminated source (unitless). Assumes skin contact occurs only while receptors are awake, and the park is the only contaminated area of interest.
EF = Exposure frequency in days per year, i.e., "days/week x weeks/year."
ED = Exposure duration in years.
BW = Body weight in kilograms.
AT = Averaging time: period over which exposure is averaged, in days. For carcinogens, AT typically is a human lifetime in days, which is "365 days/year x 70 years."

Calculation of "Absorbed Dose" was broken up into several components, for simplifying exposure calculations, as follows:

1. First, the total period of exposure, in days, was calculated, as follows:

$$FI \times EF \times ED = \text{Total Days Exposed}$$

Where:

FI = hours exposed/hours awake per day
EF = days/week x weeks/year exposed
ED = duration of exposure period, in years.

The "Total Days Exposed" was calculated for three age groups, 1 through 5 years, 6 years, and 7 through 17 years, according to weekday or weekend activities. The Age 6 group was treated separately, as follows: six year old children are assumed to go to school along with the older children, but the default value for soil ingestion used in the other Appendices for 6 year old children was identical to that for younger children and different from that for children of age 7 and older. Therefore, to be consistent with the soil ingestion scenarios in the other Appendices, the six year old group was not included with either the 1 through 5 year old children or those of age 7 through 17, but was treated separately.

Ages 1 through 5

FI x EF x ED = Total Days Exposed: Ages 1 Through 5

Where:

FI = hours awake at home/total hours awake per day. Time awake is assumed to average 12 hours/day for this age group, all of which is spent at home. Therefore, FI = 12 hours home/12 hours awake.

EF = days at home/week x weeks at home/year. Assume child is home for entire day, 7 days/week for 49 weeks/year.

ED = 5 years (age 1 through 5).

The "Total Days Exposed" is as follows:
12 hours/12 hours x 7 days/week x 49 weeks/year x 5 years = 1,715 Days

Age 6

FI x EF x ED = Total Days Exposed: Age 6

Weekdays Exposed During Schoolyear, Where:

FI = hours awake at home/total hours awake per day. Time awake is assumed to average 13 hours/day for this age group, with 8 hours/day spent at school. Therefore, hours awake at home = 13-8 = 5 hours, and FI = 5 hours awake at home/13 hours awake.

EF = days at home/week x weeks at home/year. Assume child is home for 5 weekdays/week, 36 weeks/year.

ED = 1 year (age 6 only).

The "Total Weekdays Exposed" is as follows:
5 hours/13 hours x 5 days/week x 36 weeks/year x 1 year = 69.2 Days

Weekends Exposed During Schoolyear, Where:

FI = hours awake at home/total hours awake per day. Time awake is assumed to average 13 hours/day for this age group, all of which is spent at home. Therefore, FI = 13 hours home/13 hours awake.

EF = days at home/week x weeks at home/year. Assume child is home for 2 weekend days/week for 36 weeks/year.

ED = 1 year (age 6 only).

The "Total Weekend Days Exposed" is as follows:
13 hours/13 hours x 2 days/week x 36 weeks/year x 1 years = 72.0 Days

Vacation From School Exposure, Where:

FI = hours awake at home/total hours awake per day. Time awake is assumed to average 13 hours/day for this age group, 11 hours of which is spent at home (with 2 hours/day spent at a park or friend's residence). Therefore, FI = 11 hours at home/13 hours awake.

EF = days at home/week x weeks at home/year. Assume that child is home for all 7 days/week during school vacation for 13 weeks/year.

ED = 1 year (age 6 only).

The "Total Vacation Days Exposed" is as follows:
11 hours/13 hours x 7 days/week x 13 weeks/year x 1 year = 77.0 Days

Total Days Exposed = Weekdays + Weekends + School Vacation

= 69.2 days + 72.0 days + 77.0 days

= 218.2 days

Ages 7 Through 17

FI x EF x ED = Total Days Exposed: Ages 7 Through 17

Weekdays Exposed During Schoolyear, Where:

FI = hours awake at home/total hours awake per day. Time awake is assumed to average 16 hours/day for this age group, with 8 hours/day spent at school. Therefore, hours awake at home = 16-8 = 8 hours, and FI = 8 hours awake at home/16 hours awake.

EF = days at home/week x weeks at home/year. Assume child is home for 5 weekdays/week, 36 weeks/year.

ED = 11 years (age 7 through 17).

The "Total Weekdays Exposed" is as follows:
8 hours/16 hours x 5 days/week x 36 weeks/year x 11 years = 990.0 Days

Weekends Exposed During Schoolyear, Where:

FI = hours awake at home/total hours awake per day. Time awake is assumed to average 16 hours/day for this age group, 13 hours of which is spent at home (with 3 hours/day spent at a park or friend's residence). Therefore, FI = 13 hours home/16 hours awake.

EF = days at home/week x weeks at home/year. Assume child is home for 2 weekend days/week for 36 weeks/year.

ED = 11 years (age 7 through 17).

The "Total Weekend Days Exposed" is as follows:
13 hours/16 hours x 2 days/week x 36 weeks/year x 11 years = 643.5 Da ys

Vacation From School Exposure, Where:

FI = hours awake at home/total hours awake per day. Time awake is assumed to average 16 hours/day for this age group, with 8 hours/day spent at home (and 8 hours/day at the park, beach, or friend's residence). Therefore, FI = 8 hours at home/16 hours awake.

EF = days at home/week x weeks at home/year. Assume child is home for all 7 days/week during school vacation for 13 weeks/year.

ED = 11 years (age 7 through 17).

The "Total Vacation Days Exposed" is as fol lows:
8 hours/16 hours x 7 days/week x 13 weeks/year x 11 years = 500.5 Days

Total Days Exposed = Weekdays + Weekends + School Vacation

= 990.0 days + 643.5 days + 500.5 days

= 2,134.0 days

2. "Total Soil Dose" is then calculated, as follows:

$$\text{Total Soil Dose} = \frac{\text{Total Days Exposed x SA x AF}}{\text{BW}}$$

Where:

SA = 4040 cm^2/day for ages 1 through 5 throughout year.
= 4970 cm^2/day for age 6
= 8010 cm^2/day for ages 7 through 17.

AF = 0.5 mg soil/cm^2 skin

BW= 15.0 kg for ages 1 through 5, 21.5 kg for age 6, and 43.5 kg for ages 7 through 17.

Ages 1 Through 5

$$\text{Total Soil Dose} = \frac{1{,}715.0 \text{ days x } 4040 \text{ cm}^2\text{/day x } 0.5 \text{ mg soil/cm}^2 \text{ skin}}{15.0 \text{ kg}}$$

= 230,953.3 mg soil/kg body weight

Age 6

$$\text{Total Soil Dose} = \frac{218.2 \text{ days x } 4970 \text{ cm}^2\text{/day x } 0.5 \text{ mg soil/cm}^2 \text{ skin}}{21.5 \text{ kg}}$$

= 25,219.9 mg soil/kg body weight

Ages 7 Through 17

$$\text{Total Soil Dose} = \frac{2134.0 \text{ days x } 8010 \text{ cm}^2\text{/day x } 0.5 \text{ mg soil/cm}^2 \text{ skin}}{43.5 \text{ kg}}$$

= 196,475.1 mg soil/kg body weight

Total Soil Dose Ages 1 Through 17
= (230,953.3 + 25,219.9 + 196,475.1) mg soil/kg
= 452,648 mg soil/kg body weight

3. This dose of soil averaged over a lifetime ("Lifetime Average Daily Dose of Soil;" $LADD_{soil}$) is calculated as follows:

$$LADD_{soil} = \frac{\text{Total Soil Dose}}{AT}$$

Where:
Total Soil Dose = 452,648 mg soil/kg body weight
AT = 365 days/year x 70 years

$$LADD_{soil} = \frac{452{,}648 \text{ mg soil/kg body weight}}{365 \text{ days/year} \times 70 \text{ years}}$$

$$= 17.716 \text{ mg soil/kg body weight-day}$$

4. The absorbed dose of DDT_{tot} averaged over a lifetime ("Lifetime Average Daily Dose of DDT_{tot}; $LADD_{DDT}$) is as follows:

$$LADD_{DDT} = LADD_{soil} \times CS \times CF \times ABS$$

Where:

$LADD_{soil}$ = 17.716 mg soil/kg body weight-day
CS = 1 mg DDT_{tot}/kg soil
CF = 10-6 kg/mg
ABS = 0.05

$$LADD_{DDT} = 17.716 \text{ mg soil/kg-day} \times 1 \text{ mg } DDT_{tot}\text{/kg soil} \times 10\text{-}6 \text{ kg/mg} \times 0.05$$

$$= 0.886\text{x}10\text{-}6 \text{ mg } DDT_{tot}\text{/kg-day}$$

$$= 8.86\text{x}10\text{-}7 \text{ mg } DDT_{tot}\text{/kg-day}$$

Note, in this example, that $LADD_{DDT}$ is equivalent to "Absorbed Dose" in the equation adapted from USEPA.

APPENDIX 12

COMMUNITY PARK - SOIL INGESTION CHILDREN OF AGES 1 THROUGH 17

1 ASSUMPTIONS

1.1 Children visit park on a periodic basis from age 1 through 17, for a total exposure period of 17 years.

1.2 Time spent at park:

1.2.1 Ages 1 through 5: 1 hour/day, 4 days/week, 49 weeks/year.

1.2.2 Ages 6 through 17:
Schoolyear weekdays: 2 hours/day, 3 days/week, 36 weeks/year.
Schoolyear weekends: 2 hours/day, 2 days/week, 36 weeks/year.
Note: A school year of 36 weeks is based on California requirements that public schools must have classes for about 180 days per year (180 days -- 5 days/week = 36 weeks).
Vacation from school: 4 hours/day, 4 days/week, 13 weeks/year.
Note: All age groups are away from home for 3 weeks per year for holidays and vacations.

1.3 Soil ingestion is 200 mg/day for all ages. Note that USEPA recommends 200 mg/day for ages 1 through 6, and 100 mg/day for ages 7 and older (USEPA, 1989a, Page 6-40 ; USEPA 1989b, Pages 2-40 to 2-59). For this community park scenario, however, children of age 6 and older are assumed to engage in "rough and tumble" and competitive sport activities, which could increase the soil ingestion rate above that described by USEPA for residential exposure scenarios. Therefore, a soil ingestion value of 200 mg/day was used for that age group. Children of ages 5 and less were assumed to be accompanied by an adult and not "rough and tumble," and therefore not exceed the 200 mg/day figure recommended by USEPA.

1.4 Fraction of ingested DDT_{tot} which is absorbed systemically is 1.0, i.e., 100 percent. One-hundred percent oral absorption of soil-borne DDT_{tot} is assumed, in the absence of experimental information.

1.5 Body weight values = means of fiftieth percentile values for males and females, combined (USEPA, 1989b, Pages 5-44 and 5-45):
Ages 1 -> 5 = 15.0 kg
Age 6 = 21.5 kg
Ages 7 -> 17 = 43.5 kg

1.6 Concentration of DDT_{tot} in soil = 1 ppm = 1 mg DDT_{tot}/kg soil.

1.7 Exposure to contaminated soil occurs only while children are in the park.

2 CALCULATIONS

Calculations were based on the following equation adapted from USEPA (USEPA, 1989a, Page 6-40):

$$\text{Intake} = \frac{CS \times CF \times IR \times ABS \times FI \times EF \times ED}{BW \times AT}$$

Where:

Intake = Daily dose of DDT_{tot} averaged over a lifetime, in mg/kg-day. Also known as "Lifetime Average Daily Dose."
CS = DDT_{tot} concentration in soil, in mg DDT_{tot}/kg soil.
CF = Conversion factor = 10-6 kg/mg.
IR = Soil ingestion rate, in mg soil/day.
ABS = Fraction of soil-borne DDT_{tot} absorbed systemically (unitless), i.e., percent absorbed/100.
FI = Fraction of soil per day coming from contaminated source (unitless). Assumes soil ingestion occurs only while receptors are awake, and the park is the only contaminated area of interest.
EF = Exposure frequency in days per year, i.e., "days/week x weeks/year."
ED = Exposure duration in years.
BW = Body weight in kilograms.
AT = Averaging time = period over which exposure is averaged, in days. For carcinogens, AT typically is a human lifetime in days, which is "365 days/year x 70 years."

Calculation of "Intake" was broken up into several components, for simplifying exposure calculations, as follows:

1. First, the total period of exposure, in days, was calculated, as follows:

$$FI \times EF \times ED = \text{Total Days Exposed}$$

Where:

FI = hours at park per day/hours awake per day.
EF = days/week x weeks/year exposed
ED = duration of exposure period, in years.

The "Total Days Exposed" was calculated for three age groups, 1 through 5 years, 6 years, and 7 through 17 years, according to weekday or weekend activities. The Age 6 group was treated separately, as follows: six year old children were assumed to go to school along with the older children, but the default value for soil ingestion in 6 year olds was identical to that for younger children and different from that for children of age 7 and older. Therefore, for the purposes of this example, the six year old group was not included with either the 1 through 5 year old children or those of age 7 through 17, but was treated separately.

Ages 1 through 5

FI x EF x ED = Total Days Exposed: Ages 1 Through 5

Where:

FI = hours in park per day/total hours awake per day. The total time awake is assumed to average 12 hours/day for this age group, with 1 hour/day spent at the park accompanied by an adult. Therefore, FI = 1 hour in park/12 hours awake.

EF = days at park/week x weeks at park/year. Assume that an adult takes the child to the park 4 days/week, 49 weeks/year.

ED = 5 years (age 1 through 5).

The "Total Days Exposed" is as follows:
1 hour/12 hours x 4 days/week x 49 weeks/year x 5 years = 81.7 Days

Age 6

FI x EF x ED = Total Days Exposed: Age 6

Weekdays Exposed During Schoolyear, Where:

FI = hours in park per day/total hours awake per day. Time awake is assumed to be 13 hours/day for this age group, with 2 hours/day spent at the park accompanied by other children. Therefore, FI = 2 hours in park/13 hours awake.

EF = days at park/week x weeks at park/year. Assume child visits the park 3 days/week x 36 weeks/year.

ED = 1 year (age 6 only).

The "Total Weekdays Exposed " is as follows:
2 hours/13 hours x 3 days/week x 36 weeks/year x 1 year = 16.6 Days

Weekends Exposed During Schoolyear, Where:

FI = hours in park per day/total hours awake per day. The total time awake is assumed to be 13 hours/day for this age group, with 2 hours/day spent at the park accompanied by adults or other children. Therefore, FI = 2 hours in park/13 hours awake.

EF = days at park/week x weeks at park/year. Assume that the child visits the park 2 days/week x 36 weeks/year.

ED = 1 year (age 6 only).

The Total Weekend Days Exposed is as follows:

2 hours/13 hours x 2 days/week x 36 weeks/year x 1 year = 11.1 Days

Vacation From School, Where:

FI = hours in park per day/total hours awake per day. The total time awake is assumed to be 13 hours/day for this age group, with 4 hours/day spent at the park accompanied by adults or other children. Therefore, FI = 4 hours in park/13 hours awake.

EF = days at park/week x weeks at park/year.
= 4 days/week x 13 weeks/year.

ED = 1 year (age 6 only).

The "Total Vacation Days Exposed" is as follows:
4 hours/13 hours x 4 days/week x 13 weeks/year x 1 year = 16.0 Days

Total Days Exposed = Weekdays + Weekends + School Vacation

= 16.6 Days + 11.1 Days + 16.0 Days

= 43.7 Days

Ages 7 Through 17

FI x EF x ED = Total Days Exposed: Ages 7 Through 17

Weekdays Exposed During Schoolyear, Where:

FI = hours in park per day/total hours awake per day. The total time awake is assumed to be 16 hours/day for this age group, with 2 hours/day spent at the park accompanied by other children. Therefore, FI = 2 hours in park/16 hours awake.

EF = days at park/week x weeks at park/year
= 3 days/week x 36 weeks/year.

ED = 11 years (age 7 through 17).

The "Total Weekdays Exposed" is as follows:
2 hours/16 hours x 3 days/week x 36 weeks/year x 11 years = 148.5 Days

Weekends Exposed During Schoolyear, Where:

FI = hours in park per day/total hours awake per day. The total time awake is assumed to be 16 hours/day for this age group, with 2 hours/day spent at the park. Therefore, FI = 2 hours in park/16 hours awake.

EF = days at park/week x weeks at park/year.
= 2 days/week x 36 weeks/year.

ED = 11 years (age 7 through 17).

The "Total Weekend Days Exposed" is as follows:
2 hours/16 hours x 2 days/week x 36 weeks/year x 11 years = 99.0 Days

Vacation From School, Where:

FI = hours in park per day/total hours awake per day. The total time awake is assumed to be 16 hours/day for this age group, with 4 hours/day spent at the park. Therefore, FI = 4 hours in park/16 hours awake.

EF = days at park/week x weeks at park/year.
= 4 days/week x 13 weeks/year.

ED = 11 years (age 7 through 17).

The "Total Vacation Days Exposed" is as follows:
4 hours/16 hours x 4 days/week x 13 weeks/year x 11 years = 143.0 Days

Total Days Exposed = Weekdays + Weekends + School Vacation

= 148.5 Days + 99.0 Days + 143.0 Days

= 390.5 Days

2. Total Soil Dose" is then calculated, as follows:

$$\text{Total Soil Dose} = \frac{\text{Total Days Exposed x IR}}{\text{BW}}$$

Where:

IR = 200 mg/day for all ages.

BW = 15.0 kg for ages 1 through 5, 21.5 kg for age 6, and 43.5 kg for ages 7 through 17.

Ages 1 Through 5

$$\text{Total Soil Dose} = \frac{\text{81.7 days x 200 mg soil/day}}{\text{15.0 kg}}$$

= 1,089.3 mg soil/kg body weight

Age 6

$$\text{Total Soil Dose} = \frac{43.7 \text{ days x } 200 \text{ mg soil/day}}{21.5 \text{ kg}}$$

$$= 406.5 \text{ mg soil/kg body weight}$$

Ages 7 Through 17

$$\text{Total Soil Dose} = \frac{390.5 \text{ days x } 200 \text{ mg soil/day}}{43.5 \text{ kg}}$$

$$= 1{,}795.4 \text{ mg soil/kg body weight}$$

Total Soil Dose: Ages 1 Through 17 = (1,089.3 + 406.5 + 1,795.4) mg soil/kg

= 3,291 mg soil/kg body weight

3. This dose of soil averaged over a lifetime ("Lifetime Average Daily Dose of Soil;" $LADD_{soil}$) is calculated as follows:

$$LADD_{soil} = \frac{\text{Total Soil Dose}}{\text{AT}}$$

Where:

Total Soil Dose = 3,291 mg soil/kg body weight
AT = 365 days/year x 70 years

$$LADD_{soil} = \frac{3{,}291 \text{ mg soil/kg body weight}}{365 \text{ days/year x } 70 \text{ years}}$$

$$= 0.129 \text{ mg soil/kg body weight-day}$$

4. The absorbed dose of DDT_{tot} averaged over a lifetime ("Lifetime Average Daily Dose of DDT_{tot}; $LADD_{DDT}$) is as follows:

$$LADD_{DDT} = LADD_{soil} \times CS \times CF \times ABS$$

Where:

$LADD_{soil}$ = 0.129 mg soil/kg body weight-day
CS = 1 mg DDT_{tot}/kg soil
CF = 10-6 kg/mg
ABS = 1.0

$LADD_{DDT}$ = 0.129 mg soil/kg-day x 1 mg DDT_{tot}/kg soil x 10-6 kg/mg x 1.0

= 0.129x10-6 mg DDT_{tot}/kg-day

= 1.29x10-7 mg DDT_{tot}/kg-day

Note, in this example, that $LADD_{DDT}$ is equivalent to "Intake" in the equation adapted from USEPA.

APPENDIX 13

COMMUNITY PARK - DERMAL SOIL EXPOSURE
INDIVIDUALS OF AGES 1 THROUGH 17

1 ASSUMPTIONS

1.1 Children visit park on a periodic basis from age 1 through 17, for a t otal exposure period of 17 years.

1.2 Time spent at park:

1.2.1 Ages 1 through 5: 1 hour/day, 4 days/week, 49 weeks/year.

1.2.2 Ages 6 through 17:

Schoolyear weekdays: 2 hours/day, 3 days/week, 36 weeks/year.

Schoolyear weekends: 3 hours/day, 2 days/week, 36 weeks/year.

Note: A school year of 36 weeks is based on California requirements that public schools must have classes for about 180 days per year (180 days - 5 days/week = 36 weeks).

Vacation from school: 4 hours/day, 4 days/week, 13 weeks/year.

Note: All age groups are away from home for 3 weeks per year for holidays and vacations.

1.3 Body parts and surface area of skin exposed to soil - age and activity specific - based on best estimate of data from USEPA (USEPA, 1989b, Pages 4-12 and 13, and 4-30 and 31).

All days - head and hands:

Ages 1 -> 5 = 1400 cm^2

Weekdays - head and hands:

Age 6 = 1520 cm^2

Ages 7 -> 17 = 2050 cm^2

Weekends and school vacation - head, hands, arms, and legs:

Age 6 = 4970 cm^2

Ages 7 -> 17 = 8010 cm^2

Assume that children in the 1 through 5 year old group are accompanied by parents and do not engage in rough play activities or have different clothing covering on weekends than on weekdays.

1.4 Factor for adherence of soil t o skin = 0.5 mg soil/m^2 (see Sedman, 1989, for discussion).

1.5 Fraction of soil-borne DDT_{tot} which is absorbed systemically through the skin in 24 hours (dermal absorption) is 0.05, i.e., 5 percent. Five percent dermal absorption of soil-borne DDT_{tot} is based on the data of Wester et al (1990).

1.6 Body weight values - means of fiftieth percentile values for males and females, combined (USEPA, 1989b, Pages 5-44 and 5-45):

Ages 1 -> 5 = 15.0 kg

Age 6 = 21.5 kg

Ages 7 -> 17 = 43.5 kg

1.7 Concentration of DDT_{tot} in soil = 1 ppm = 1 mg DDT_{tot}/kg soil.
1.8 Exposure to contaminated soil occurs only while children are in the park.

2 CALCULATIONS

Calculations were based on the following equation adapted from USEPA (USEPA, 1989a, Page 6-41):

$$\text{Absorbed Dose} = \frac{CS \times CF \times SA \times AF \times ABS \times FI \times EF \times ED}{BW \times AT}$$

Where:

Absorbed Dose = Daily dose of DDT_{tot} averaged over a lifetime, in mg/kg-day. Also known as "Lifetime Average Daily Dose."
CS = DDT_{tot} concentration in soil, in mg DDT_{tot}/kg soil
CF = Conversion factor = 10-6 kg/mg
SA = Surface area of skin exposed to soil = cm^2 skin/day
AF = Adherence factor of soil to skin = mg soil/cm^2 skin
ABS = Fraction of soil-borne DDT_{tot} absorbed systemically (unitless), i.e., percent absorbed/100.
FI = Fraction of soil per day coming from contaminated source (unitless). Assumes skin contact occurs only while receptors are awake, and the park is the only contaminated area of interest.
EF = Exposure frequency in days per year, i.e., "days/week x weeks/year."
ED = Exposure duration in years.
BW = Body weight in kilograms.
AT = Averaging time: period over which exposure is averaged, in days. For carcinogens, AT typically is a human lifetime in days, which is "365 days/year x 70 years."

Calculation of "Absorbed Dose" was broken up into several components, for simplifying exposure calculations, as follows:

1. First, the total period of exposure, in days, was calculated, as follows:

$$FI \times EF \times ED = \text{Total Days Exposed}$$

Where:

FI = hours exposed/hours awake per day
EF = days/week x weeks/year exposed
ED = duration of exposure period, in years.

The "Total Days Exposed" was calculated for three age groups, 1 through 5 years, 6 years, and 7 through 17 years, according to weekday or weekend activities. The Age 6 group was treated separately, as follows: six year old children are assumed to go to school along with the older children, but the default value for soil ingestion used in the other Appendices for 6 year old children was identical to that for younger children and different from that for children of age 7 and older. Therefore, to be consistent with the soil ingestion scenarios in the other Appendices, the six-year-old group was not included with either the 1 through 5-year-old children or those of age 7 through 17, but was treated separately.

Ages 1 through 5

FI x EF x ED = Total Days Exposed: Ages 1 Through 5

Where:

FI = hours in park per day/total hours awake per day. Time awake is assumed to average 12 hours/day for this age group, with 1 hour/day spent at the park accompanied by an adult. Therefore, FI = 1 hour in park/12 hours awake.

EF = days at park/week x weeks at park/year. Assume adult takes child to park 4 days/week for 49 weeks/year.

ED = 5 years (age 1 through 5).

The "Total Days Exposed" is as follows:
1 hour/12 hours x 4 days/week x 49 weeks/year x 5 years = 81.7 Days

Age 6

FI x EF x ED = Total Days Exposed: Age 6

Weekdays Exposed During Schoolyear, Where:

FI = hours in park per day/total hours awake per day. Time awake is assumed to average 13 hours/day for this age group, with 2 hours/day spent at the park after school accompanied by other children. Therefore, FI = 2 hours in park/13 hours awake.

EF = days at park/week x weeks at park/year. Assume child visits park 3 days/week after school for 36 weeks/year.

ED = 1 year (age 6 only).

The "Total Weekdays Exposed" is as follows:
2 hours/13 hours x 3 days/week x 36 weeks/year x 1 year = 16.6 Days

Weekends Exposed During Schoolyear, Where:

FI = hours in park per day/total hours awake per day. Time awake is assumed to average 13 hours/day for this age group, with 2 hours/day spent at the park accompanied by adults or other children. Therefore, FI = 2 hours in park/13 hours awake.

EF = days at park/week x weeks at park/year. Assume child visits park 2 days/week during weekend for 36 weeks/year.

ED = 1 year (age 6 only).

The "Total Weekend Days Exposed" is as follows:
2 hours/13 hours x 2 days/week x 36 weeks/y ear x 1 years = 11.1 Days

Vacation From School Exposure, Where:

FI = hours in park per day/total hours awake per day. Time awake is assumed to average 13 hours/day for this age group, with 4 hours/day spent at the park accompanied by adults or other children. Therefore, FI = 4 hours in park/13 hours awake.

EF = days at park/week x weeks at park/year. Assume child visits park 4 days/week during school vacation for 13 weeks/year.

ED = 1 year (age 6 only).

The "Total Vacation Days Exposed" is as follow s:
4 hours/13 hours x 4 days/week x 13 weeks/year x 1 year = 16.0 Days

Total Days Exposed = Weekdays + Weekends + School Vacation

= 16.6 days + 11.1 days + 16.0 days

= 43.7 days

Ages 7 Through 17

FI x EF x ED = Total Days Exposed: Ages 7 Through 17

Weekdays Exposed During Schoolyear, Where:

FI = hours in park per day/total hours awake per day. Time awake is assumed to average 16 hours/day for this age group, with 2 hours/day spent at the park after school accompanied by other children. Therefore, FI = 2 hours in park/16 hours awake.

EF = days at park/week x weeks at park/year. Assume child visits park 3 days/week after school for 36 weeks/year.

ED = 11 years (age 7 through 17).

The "Total Weekdays Exposed" is as follows:
2 hours/16 hours x 3 days/week x 36 weeks/year x 11 years = 148.5 Days

Weekends Exposed During Schoolyear, Where:

FI = hours in park per day/total hours awake per day. Time awake is assumed to average 16 hours/day for this age group, with 2 hours/day spent at the park accompanied by adults or other children. Therefore, FI = 2 hours in park/16 hours awake.

EF = days at park/week x weeks at park/year. Assume child visits park 2 days/week during weekend for 36 weeks/year.

ED = 11 years (age 7 through 17).

The "Total Weekend Days Exposed" is as follows:
2 hours/16 hours x 2 days/week x 36 weeks/year x 11 y ears = 99.0 Days

Vacation From School Exposure, Where:

FI = hours in park per day/total hours awake per day. Time awake is assumed to average 16 hours/day for this age group, with 4 hours/day spent at the park accompanied by adults or other children. Therefore, FI = 4 hours in park/16 hours awake.

EF = days at park/week x weeks at park/year. Assume child visits park 4 days/week during school vacation for 13 weeks/year.

ED = 1 year (age 6 only).

The "Total Vacation Days Exposed" is as follows:
4 hours/16 hours x 4 days/week x 13 weeks/year x 11 years = 143.0 Days

Total Days Exposed = Weekdays + Weekends + School Vacation

= 148.5 days + 99.0 days + 143.0 days

= 390.5 days

2. "Total Soil Dose" is then calculated, as follows:

$$\text{Total Soil Dose} = \frac{\text{Total Days Exposed} \times SA \times AF}{BW}$$

Where:

SA = 1400 cm^2/day for ages 1 through 5 throughout year.

SA on weekdays = 1520 cm^2/day for age 6 and 2050 cm^2/day for ages 7 through 17.

SA on weekends and school vacations = 4970 cm^2/day for age 6 and 8010 cm^2/day for ages 7 through 17.

AF = 0.5 mg soil/cm^2 skin

BW = 15.0 kg for ages 1 through 5, 21.5 kg for age 6, and 43.5 kg for ages 7 through 17.

Ages 1 Through 5

$$\text{Total Soil Dose} = \frac{81.7 \text{ days x } 1400 \text{ cm}^2\text{/day x } 0.5 \text{ mg soil/cm}^2 \text{ skin}}{15.0 \text{ kg}}$$

$$= 3{,}812.7 \text{ mg soil/kg body weight}$$

Age 6

Weekdays

$$\text{Total Soil Dose} = \frac{16.6 \text{ days x } 1520 \text{ cm}^2\text{/day x } 0.5 \text{ mg soil/cm}^2 \text{ skin}}{21.5 \text{ kg}}$$

$$= 586.8 \text{ mg soil/kg body weight}$$

Weekends

$$\text{Total Soil Dose} = \frac{11.1 \text{ days x } 4970 \text{ cm}^2\text{/day x } 0.5 \text{ mg soil/cm}^2 \text{ skin}}{21.5 \text{ kg}}$$

$$= 1{,}283.0 \text{ mg soil/kg body weight}$$

School vacation

$$\text{Total Soil Dose} = \frac{16.0 \text{ days x } 4970 \text{ cm}^2\text{/day x } 0.5 \text{ mg soil/cm}^2 \text{ skin}}{21.5 \text{ kg}}$$

$$= 1{,}849.3 \text{ mg soil/kg body weight}$$

$$\text{Total Soil Dose Age 6} = (586.8 + 1{,}283.0 + 1{,}849.3) \text{ mg soil/kg}$$

$$= 3{,}719.1 \text{ mg soil/kg body weight}$$

Ages 7 Through 17

Weekdays

$$\text{Total Soil Dose} = \frac{148.5 \text{ days x } 2050 \text{ cm}^2\text{/day x } 0.5 \text{ mg soil/cm}^2 \text{ skin}}{43.5 \text{ kg}}$$

= 3,499.1 mg soil/kg body weight

Weekends

$$\text{Total Soil Dose} = \frac{99.0 \text{ days x } 8010 \text{ cm}^2\text{/day x } 0.5 \text{ mg soil/cm}^2 \text{ skin}}{43.5 \text{ kg}}$$

= 9,114.8 mg soil/kg body weight

School vacation

$$\text{Total Soil Dose} = \frac{143.0 \text{ days x } 8010 \text{ cm}^2\text{/day x } 0.5 \text{ mg soil/cm}^2 \text{ skin}}{43.5 \text{ kg}}$$

= 13,165.9 mg soil/kg body weight

Total Soil Dose Ages 7 Through 17
= (3,499.1 + 9,114.8 + 13,165.9) mg soil/kg
= 25,779.8 mg soil/kg body weight

Total Soil Dose Ages 1 Through 17
= (3,812.7 + 3,719.1 + 25,779.8) mg soil/kg
= 33,312 mg soil/kg body weight

3. This dose of soil averaged over a lifetime ("Lifetime Average Daily Dose of Soil;" $LADD_{soil}$) is calculated as follows:

$$LADD_{soil} = \frac{\text{Total Soil Dose}}{AT}$$

Where:

Total Soil Dose = 33,312 mg soil/kg body weight
AT = 365 days/year x 70 years

$$LADD_{soil} = \frac{33{,}312 \text{ mg soil/kg body weight}}{365 \text{ days/year x } 70 \text{ years}}$$

$$= 1.304 \text{ mg soil/kg body weight-day}$$

4. The absorbed dose of DDT_{tot} averaged over a lifetime ("Lifetime Average Daily Dose of DDT_{tot}; $LADD_{DDT}$) is as follows:

$$LADD_{DDT} = LADD_{soil} \text{ x CS x CF x ABS}$$

Where:

$LADD_{soil}$ = 1.304 mg soil/kg body weight-day
CS = 1 mg DDT_{tot}/kg soil
CF = 10-6 kg/mg
ABS = 0.05

$$LADD_{DDT} = 1.304 \text{ mg soil/kg-day x 1 mg } DDT_{tot}\text{/kg soil x 10-6 kg/mg x 0.05}$$

$$= 0.0652\text{x10-6 mg } DDT_{tot}\text{/kg-day}$$

$$= 6.52\text{x10-8 mg } DDT_{tot}\text{/kg-day}$$

Note, in this example, that $LADD_{DDT}$ is equivalent to "Absorbed Dose" in the equation adapted from USEPA.

APPENDIX 14

SOIL INGESTION EXPOSURE AT SCHOOL CHILDREN AGES 1 THROUGH 17

1 ASSUMPTIONS

1.1 Children attend school at the same location from grades 1 through 12, from ages 6 through 17.

1.2 Time spent at school: 8 hours/day, 180 days/year, for 12 years.

Note: A school year of 180 days is based on California requirements for public schools to receive State funding.

1.3 Average soil ingestion rate is 110 mg/day for ages 6 through 17, which represents a combination of the 200 mg/day for 6 year olds and the 100 mg/day figure for individuals 7 years and older, recommended by USEPA (1989a, Page 6-40)

1.4 Factor for adherence of soil to skin = 0.5 mg soil/cm ^{2} (see Sedman, 1989, for discussion).

1.5 Fraction of soil-borne DDT_{tot} which is absorbed systemically from ingested soil = 1.0, i.e., 100 percent. One hundred percent oral absorption of soil-borne DDT_{tot} is assumed, in the absence of experimental information obtained with soil as the medium of exposure.

1.6 Body weight values = means of fiftieth percentile values for males and females, combined (USEPA, 1989b, Pages 5-44 and 5-45): Ages 6 through 17 = 41.6 kg

1.7 Concentration of DDT_{tot} in soil = 1 ppm = 1 mg DDT_{tot}/kg soil.

1.8 Exposure to contaminated occurs only while children are at school.

2 CALCULATIONS

Calculations were based on the following equation adapted from USEPA (USEPA, 1989a, Page 6-41):

$$\text{Intake} = \frac{CS \times CF \times IR \times FI \times ABS \times EF \times ED}{BW \times AT}$$

Where:

Intake = Daily dose of DDT_{tot} averaged over a lifetime, in mg/kg-day. Also known as "Lifetime Average Daily Dose."

CS = DDT_{tot} concentration in soil, in mg DDT_{tot}/kg soil

CF = Conversion factor = 10-6 kg/mg

IR = Soil ingestion rate, in mg/day

ABS = Fraction of soil-borne DDT_{tot} absorbed systemically (unitless), i.e., percent absorbed/100.
FI = Fraction of soil per day coming from contaminated source (unitless). Assumes soil ingestion occurs only while receptors are awake, and the school property is the only contaminated area of interest.
EF = Exposure frequency in days per year.
ED = Exposure duration in years.
BW = Body weight in kilograms.
AT = Averaging time: period over which exposure is averaged, in days. For carcinogens, AT typically is a human lifetime in days, which is "365 days/year x 70 years."

Calculation of "Intake" was broken up into several components, for simplifying exposure calculations, as follows:

1. First, the total period of exposure, in days, was calculated, as follows:

$$FI \times EF \times ED = \text{Total Days Exposed}$$

Where:

FI = hours at school/total hours awake per day. Time awake is assumed to average 16 hours/day for this age group, and 8 hours/day are spent at school. Therefore, FI = 8 hours at school/16 hours awake.
EF = days at school/year, which is a total of 180 days.
ED = 12 years (age 6 through 17 ; grades 1 through 12).

The "Total Days Exposed" for each of two dress patterns is as follows:
8 hours/16 hours x 180 days/year x 12 years = 1080 Days

2. "Total Soil Dose" is then calculated, as follows:

$$\text{Total Soil Dose} = \frac{\text{Total Days Exposed} \times IR}{BW}$$

Where:

Total Days Exposed = 1080 days
IR = 110 mg soil/day
BW= 41.6 kg

$$\text{Total Soil Dose} = \frac{1{,}080 \text{ days x } 110 \text{ mg soil/day}}{41.6 \text{ kg}}$$

$$= 2{,}856 \text{ mg soil/kg body weight}$$

3. This dose of soil averaged over a lifetime ("Lifetime Average Daily Dose of Soil;" $LADD_{soil}$) is calculated as follows:

$$LADD_{soil} = \frac{\text{Total Soil Dose}}{AT}$$

Where:

Total Soil Dose = 2,856 mg soil/kg body weight
AT = 365 days/year x 70 years

$$LADD_{soil} = \frac{2{,}856 \text{ mg soil/kg body weight}}{365 \text{ days/year x } 70 \text{ years}}$$

$$= 0.112 \text{ mg soil/kg body weight-day}$$

4. The absorbed dose of DDT_{tot} averaged over a lifetime ("Lifetime Average Daily Dose of DDT_{tot}; $LADD_{DDT}$) is as follows:

$$LADD_{DDT} = LADD_{soil} \text{ x CS x CF x ABS}$$

Where:

$LADD_{soil}$ = 0.112 mg soil/kg body weight-day
CS = 1 mg DDT_{tot}/kg soil
CF = 10-6 kg/mg
ABS = 1.0

$$LADD_{DDT} = 0.112 \text{ mg soil/kg-day x } 1 \text{ mg } DDT_{tot}\text{/kg soil x } 10\text{-}6 \text{ kg/mg x } 1.0$$

$$= 0.112\text{x}10\text{-}6 \text{ mg } DDT_{tot}\text{/kg-day}$$

$$= 1.12\text{x}10\text{-}7 \text{ mg } DDT_{tot}\text{/kg-day}$$

Note, in this example, that $LADD_{DDT}$ is equivalent to "Intake" in the equation adapted from USEPA.

APPENDIX 15

DERMAL SOIL EXPOSURE AT SCHOOL CHILDREN AGES 1 THROUGH 17

1 ASSUMPTIONS

1.1 Children attend school at the same location from grades 1 through 12, from ages 6 through 17.

1.2 Time spent at school: 8 hours/day, 180 days/year, for 12 years.

Note: A school year of 180 days is based on California requirements for public schools to receive State funding.

1.3 Body parts and surface area of skin exposed to soil, based on best estimate of data from USEPA (USEPA, 1989b, Pages 4-12 and 13, and 4-30 and 31), for this age group:

2030 cm^2 = Head and hands, 90 days of school year, cool weather.

7740 cm^2 = Head, arms, hands, and legs, remaining 90 days of school year, warm weather.

1.4 Factor for adherence of soil to skin = 0.5 mg soil/cm^2 (see Sedman, 1989, for discussion).

1.5 Fraction of soil-borne DDT_{tot} which is absorbed systemically through the skin in 24 hours (dermal absorption) is 0.05, i.e., 5 percent. Five percent dermal absorption of soil-borne DDT_{tot} is based on the data of Wester et al (1990).

1.6 Body weight values = means of fiftieth percentile values for males and females, combined (USEPA, 1989b, Pages 5-44 and 5-45): Ages 6 through 17 = 41.6 kg.

1.7 Concentration of DDT_{tot} in soil = 1 ppm = 1 mg DDT_{tot}/kg soil.

1.8 Exposure to contaminated occurs only while children are at school.

2 CALCULATIONS

Calculations were based on the following equation adapted from USEPA (USEPA, 1989a, Page 6-41):

$$\text{Absorbed Dose} = \frac{CS \times CF \times SA \times AF \times ABS \times FI \times EF \times ED}{BW \times AT}$$

Where:

Absorbed Dose = Daily dose of DDT_{tot} averaged over a lifetime, in mg/kg-day. Also known as "Lifetime Average Daily Dose."

CS = DDT_{tot} concentration in soil, in mg DDT_{tot}/kg soil

CF = Conversion factor = 10-6 kg/mg

SA = Surface area of skin exposed to soil = cm^2 skin/day
AF = Adherence factor of soil to skin = mg soil/cm^2 skin
ABS = Fraction of soil-borne DDT_{tot} absorbed systemically (unitless), i.e., percent absorbed/100.
FI = Fraction of soil per day coming from contaminated source (unitless). Assumes skin contact occurs only while receptors are awake, and the school grounds are the only contaminated areas of interest.
EF = Exposure frequency in days per year, i.e., "days/week x weeks/year."
ED = Exposure duration in years.
BW = Body weight in kilograms.
AT = Averaging time: period over which exposure is averaged, in days. For carcinogens, AT typically is a human lifetime in days, which is "365 days/year x 70 years."

Calculation of "Absorbed Dose" was broken up into several components, for simplifying exposure calculations, as follows:

1. First, the total period of exposure, in days, was calculated, as follows:

$$FI \times EF \times ED = \text{Total Days Exposed}$$

Where:

FI = hours at school/total hours awake per day. Time awake is assumed to average 16 hours/day for this age group, and 8 hours/day are spent at school. Therefore, FI = 8 hours home/16 hours awake.
EF = days at school/year, which is a total of 180 days, divided into two 90 day segments, between which students change dress according to weather changes.
ED = 12 years (age 6 through 17 ; grades 1 through 12).

The "Total Days Exposed" for each of the two dress segments is as follows:
8 hours/16 hours x 90 days/year x 12 years = 540 Days

2. "Total Soil Dose" is then calculated, as follows:

$$\text{Total Soil Dose} = \frac{\text{Total Days Exposed} \times SA \times AF}{BW}$$

Where:

Total Days Exposed = 540 days per dress period

SA = 2030 cm^2/day for 90 days when dressing for cool weather in "long clothes."

= 7740 cm^2/day for 90 days when dressing for warm weather in shorts and short sleeve shirts.

AF = 0.5 mg soil/cm^2 skin

BW = 41.6 kg

Exposure While Dressed in "Long Clothes:"

$$\text{Total Soil Dose} = \frac{540 \text{ days} \times 2030 \text{ cm}^2\text{/day} \times 0.5 \text{ mg soil/cm}^2 \text{ skin}}{41.6 \text{ kg}}$$

= 13,175.4 mg soil/kg body weight

Exposure While Dressed in "Short Clothes:"

$$\text{Total Soil Dose} = \frac{540 \text{ days} \times 7740 \text{ cm}^2\text{/day} \times 0.5 \text{ mg soil/cm}^2 \text{ skin}}{41.6 \text{ kg}}$$

= 50,235.5 mg soil/kg body weight

Total Soil Dose During Grades 1 Through 12

= (13,175.4 + 50,235.5) mg soil/kg

= 63,411 mg soil/kg body weight

3. This dose of soil averaged over a lifetim e ("Lifetime Average Daily Dose of Soil;" $LADD_{soil}$) is calculated as follows:

$$LADD_{soil} = \frac{\text{Total Soil Dose}}{AT}$$

Where:

Total Soil Dose = 63,411 mg soil/kg body weight

AT = 365 days/year x 70 years

$$LADD_{soil} = \frac{63{,}411 \text{ mg soil/kg body weight}}{365 \text{ days/year} \times 70 \text{ years}}$$

$$= 2.482 \text{ mg soil/kg body weight-day}$$

4. The absorbed dose of DDT_{tot} averaged over a lifetime ("Lifetime Average Daily Dose of DDT_{tot}; $LADD_{DDT}$) is as follows:

$$LADD_{DDT} = LADD_{soil} \text{ x } CS \text{ x } CF \text{ x } ABS$$

Where:

$LADD_{soil}$ = 2.482 mg soil/kg body weight-day
CS = 1 mg DDT_{tot}/kg soil
CF = 10-6 kg/mg
ABS = 0.05

$$LADD_{DDT} = 2.482 \text{ mg soil/kg-day x 1 mg } DDT_{tot}\text{/kg soil x 10-6 kg/mg x 0.05}$$

$$= 0.124\text{x}10\text{-}6 \text{ mg } DDT_{tot}\text{/kg-day}$$

$$= 1.24\text{x}10\text{-}8 \text{ mg } DDT_{tot}\text{/kg-day}$$

Note, in this example, that $LADD_{DDT}$ is equivalent to "Absorbed Dose" in the equation adapted from USEPA.

APPENDIX 16

RESIDENTIAL INHALATION EXPOSURE
ADULT FOR 30 YEARS
HOMEMAKER OR WORKS AT HOME

1 ASSUMPTIONS

- 1.1 Adult lives at the residence for 3 0 years.
- 1.2 Time spent at residence:
  - 1.2.1 Weekdays: At home 24 hours/day, 5 days/week, for 49 weeks/year.
  - 1.2.2 Weekends: At home 20 hours/day, 2 days/week, for 49 weeks/year.
  - 1.2.3 Vacations: Away from home 24 hours/day for 3 weeks/year.
- 1.3 Ventilation rate = 20 m^3/day.
- 1.4 Total dust concentration = 200 ug/m^3
- 1.5 Concentration of dust available for alveolar deposition (particles < 10 um in size) = 50 ug/m^3
- 1.6 Systemic absorption of DDT_{tot} from alveolar dust = 100%.
- 1.7 Body weight value for adult is 70 kg (USEPA, 1989a, Page 6-40).
- 1.8 Concentration of DDT_{tot} in dust is 1 ppm = 1 mg DDT_{tot}/kg soil.

2 CALCULATIONS

Calculations were based on the following equation adapted from USEPA (USEPA, 1989a, Page 6-44):

$$\text{Intake} = \frac{CA \times CS \times CF \times IR \times ET \times EF \times ED}{BW \times AT}$$

Where:

Intake = Daily dose of DDT_{tot} averaged over a lifetime, in mg/kg-day. Also known as "Lifetime Average Daily Dose" (LADD).
CA = Concentration of dust in air, in mg/m^3
CS = Concentration of DDT_{tot} in dust, in mg/kg
CF = Conversion factor = 10-6 kg/mg
IR = Inhalation rate, in m^3/day
ET = Exposure time, in hours/day
EF = Exposure frequency, in days/year, i.e., "days/week x weeks/year."
ED = Exposure duration, in year

BW = Body weight
AT = Averaging time: period over which exposure is averaged, in days. For carcinogens, AT typically is a human lifetime in days, which in this example scenario, is "365 days/year x 70 years."

Where:

CA = 50 ug dust/m^3 = 0.05 mg dust/m^3, all of which is assumed to be respirable, i.e., particle sizes of 10 microns or less.
CS = 1 mg DDT_{tot}/kg soil
CF = 10-6 kg/mg
IR = 20 m^3/day
ET = 24 hours/day; assumes windows are open all year.
EF = 7 days/week x 49 weeks/year
ED = 30 years
BW = 70 kg
AT = 365 days/year x 70 years

Accordingly, Intake ("LADD") =

$$\text{LADD} = \frac{0.05 \text{ mg dust/m}^3 \times 1 \text{ mg DDT}_{tot}\text{/kg} \times 10\text{-}6 \text{ kg/mg} \times 20 \text{ m}^3\text{/day} \times 365 \text{ days/ yr} \times 30 \text{ yrs}}{70 \text{ kg} \times 365 \text{ days/ yr} \times 70 \text{ yrs}}$$

= 0.00612x10-6 mg DDT_{tot}/kg-day

= 6.12x10-9 mg DDT/kg-day

APPENDIX 17

INGESTION OF HOME-GROWN PRODUCE
ADULT

1 ASSUMPTIONS

1.1 Adult lives at residence for 30 years.
1.2 Adult body weight is 70 kg.
1.3 Residence has sufficient space for small garden.
1.4 Amount of homegrown produce and fruit consumed = 78 g/day.
1.5 Concentration of DDT_{tot} in soil = 1 ppm
1.6 Systemic absorption of DDT from produce/fruit = 100%.

2 CALCULATIONS

The concentration of DDT_{tot} taken up into the homegrown produce was calculated according to the following equation from CAPCOA (CAPCOA, 1992, Page E-II-9), with values for Koc and Kow taken from Superfund Public Health Evaluation Manual (USEPA, 1986, Page 122), as follows:

Ctrans = CS x UF2

Where:

Ctrans = Concentration in plant due to root uptake, in ug/kg.
CS = Concentration of DDT_{tot} in soil, in ug DDT_{tot}/kg soil.
UF2 = Uptake factor, which is calculated as follows:

UF2 = [(0.03 x Kow0.77) + 0.82]/(Koc x Foc)

Where:

0.03, 0.77, and 0.82 = Empirical constants.
Kow = Octanol:water partition coefficient. Log Kow values from USEPA (1986, Page 122):
DDT log Kow = 6.19; Kow = 1,548,817
DDE log Kow = 7.00; Kow = 10,000,000
DDD log Kow = 6.20; Kow = 1,584,893
Koc = Organic carbon partition coefficient. Values from USEPA (1986, Page 122):
DDT = 243,000
DDE = 4,400,000
DDD = 770,000
Foc = Fraction of organic carbon in the soil = 0.1 (CAPCOA, 1992, Page E-II-10).

UF2 Calculations:

$UF2_{DDT}$ = [(0.03 x 1,548,8170.77) + 0.82]/(243,000 x 0.1) = 0.08790

UF2DDE = [(0.03 x 10,000,0000.77) + 0.82]/(4,400,000 x 0.1) = 0.01674

UF2DDD = [(0.03 x 1,584,8930.77) + 0.82]/(770,000 x 0.1) = 0.02824

Ctrans Calculations:

$C_{trans\text{-}DDT}$ = 1,000 ug DDT/kg soil x 0.08790 = 87.90 ug DDT/kg plant

Ctrans-DDE = 1,000 ug DDE/kg soil x 0.01674 = 16.74 ug DDE/kg plant

Ctrans-DDD = 1,000 ug DDD/kg soil x 0.02824 = 28.24 ug DDD/kg plant

Exposure to DDT_{tot} was then calculated according to the following equation adapted from USEPA (1989b, Page 1-8 in Part II):

$$\text{Lifetime Average Daily Exposure} = \frac{C \times CR \times CF \times ED}{BW \times LT \times 365 \text{ days/year}}$$

Where:

Lifetime Average Daily Exposure = Daily dose of DDT_{tot} averaged over a lifetime, in mg/kg-day.
C = Ctrans-DDT = Contaminant concentration in produce, in mg DDT/kg produce.
CR = Consumption rate, in g produce/day.
CF = Conversion factor = 10-3 kg/g
ED = Exposure duration, in days, i.e., "days ingested/year x years"
BW = Body weight, in kg
LT = Lifetime in years

For the purposes of this exercise, DDT alone was modeled in this system, because the estimated plant uptake factor (see UF2 above) for DDT was greater than that for either DDE or DDD. CR and ED were selected from USEPA figures (1989b, Pages 1-8 through 1-11, in Part II), and represent a "typical" scenario. Accordingly:

C = Ctrans-DDT = 0.0879 mg DDT/kg produce
CR: Homegrown vegetables = 50 g/day
Homegrown fruit = 28 g/day
Total homegrown produce eaten = 78 g/day
CF = 10^{-6} kg/mg
ED = 20 percent of time, assuming long harvest periods;
= 0.2 x 365 days/year x 30 years = 2,190 days per 30 years
BW = 70 kg
LT = 70 years

Lifetime Average Daily Exposure:

$$= \frac{78 \text{ g food/day} \times 0.0879 \text{ mg DDT/kg produce} \times 10^{-3} \text{ kg/g} \times 2{,}190 \text{ days/year}}{70 \text{ kg} \times 70 \text{ yrs} \times 365 \text{ days/year}}$$

$= 0.00840 \times 10^{-3}$ mg DDT/kg-day

$= 8.40 \times 10^{-6}$ mg DDT/kg-day

APPENDIX 18

CHEMICAL ABSTRACTS SERVICE (CAS) NOMENCLATURE FOR DDT, DDD, AND DDE

o,p'-DDT
1-(o-chlorophenyl)-1-(p- chlorophenyl)-2,2-trichloroethane

m,p'-DDT
1-(m-chlorophenyl)-1-(p- chlorophenyl)-2,2-trichloroethane

p,p'-DDT (also known as 4,4-DDT)
1,1,1-trichloro-2 ,2-bis(p-chlorophenyl)ethane

o,p'-DDD
1-(o-chlorophenyl)-1-(p- chlorophenyl)-2,2-dichloroethane

m,p'-DDD
1-(m-chlorophenyl)-1-(p- chlorophenyl)-2,2-dichloroethane

p,p'-DDD (known as "TDE" in older literature)
1,1-dichloro-2 ,2-bis(p-chlorophenyl)ethane

o,p'-DDE
1-(o-chlorophenyl)-1-(p- chlorophenyl)-2,2-dichloroethene

m,p'-DDE
1-(m-chlorophenyl)-1-(p- chlorophenyl)-2,2-dichloroethene

p,p'-DDE
1,1-dichloro-2 ,2-bis(p-chlorophenyl) ethene

OSA-DDT-SOIL.10

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CHAPTER 9

A TOXICITY EQUIVALENCY FACTOR PROCEDURE FOR ESTIMATING 2,3,7,8-TETRACHLORODIBENZO-P-DIOXIN EQUIVALENTS IN MIXTURES OF POLYCHLORINATED DIBENZO-P-DIOXINS AND POLYCHLORINATED DIBENZOFURANS

ABSTRACT

Hazardous waste sites and facilities in California frequently contain mixtures of polychlorinated dibenzo-p-dioxins (PCDDs) and/or polychlorinated dibenzofurans (PCDFs). There are 210 possible isomers of PCDDs and PCDFs, but only several have received extensive toxicological testing. The most potent isomer is 2,3,7,8 tetrachloro dibenzo-p-dioxin (TCDD). With several exceptions, the toxicity and potency of the remaining structural isomers remains unknown.

Three approaches have been developed in an attempt to fill this data void: The first, DHS-TEF, developed by the California Department of Health Services (DHS 1986b), the second, EPA-TEF/87, developed by the U.S. Environmental Protection Agency (U.S. EPA 1987), and the last, NATO/CCMS I-TEF/88 developed, by an international scientific committee convened under the auspices of the North Atlantic Treaty Organization (NATO/CCMS 1988a, b). The first and last approaches assumed that only isomers in which the 2,3,7,and 8 positions were occupied with chlorines are of toxicologic concern. Various portions of the toxicity database were used by each approach to calculate a Toxicity Equivalency Factor (TEF) for each isomer of concern. The TEF permits conversion of PCDD and PCDF concentrations into a toxicologically equivalent concentration of 2,3,7,8-TCDD.

Unfortunately, each approach utilized different portions of the toxicity database. Consequently, TEF values can differ substantially between the three approaches. The NATO/CCMS I-TEF/88 approach provided the most extensive use of the database compared to its two predecessors, DHS-TEF and EPA-TEF/87. Subsequently, U.S. EPA abandoned the EPA-TEF/87 approach and endorsed the I-TEF method of NATO/CCMS for use within the Agency.

The Department of Toxic Substance Control (DTSC) will use the I-TEF method developed by NATO/CCMS and endorsed by U.S. EPA in assessing the risks of PCDDs and PCDFs. Guidance and rationale for use of the I-TEF method is provided in this guidance document. Use of the I-TEF method will minimize regulatory differences between DTSC and U.S. EPA, as well as standardize procedures within DTSC.

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Richard Becker, Ph.D., DABT

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ABBREVIATIONS AND ACRONYMS

CAG	-	Carcinogen Assessment Group at U.S. Environmental Protection Agency
DHS	-	California Department of Health Services
IRIS	-	Integrated Risk Information System: U.S. Environmental Protection Agency's on line computer database for hazardous chemicals
NATO/CCMS	-	North Atlantic Treaty Organization, Committee on the Challenges of Modern Society
NTP	-	National Toxicology Program
PCDD	-	polychlorinated dibenzo-p-dioxin
PCDF	-	polychlorinated dibenzofuran
RfD	-	Reference dose: an exposure level which is not likely to cause significant non-cancer adverse health effects.
TCDD	-	2,3,7,8-tetrachlorodibenzo-p-dioxin
TEF	-	Toxicity Equivalency Factor
TRAS	-	Toxicology and Risk Assessment Section, Technical Services Branch, California Department of Toxic Substances Control
TSCP	-	Toxic Substances Control Program, California Department of Health Services
U.S. EPA	-	U.S. Environmental Protection Agency
kg	-	kilogram
g	-	gram, one thousandth of a kilogram, $1x10^{-3}$ kg
mg	-	milligram, one-millionth of a kilogram, $1x10^{-6}$ kg
ug	-	microgram, one-billionth of a kilogram, $1x10^{-9}$ kg
ng	-	nanogram, one-trillionth of a kilogram, $1x10^{-12}$ kg
pg	-	picogram, one-quadrillionth of a kilogram, $1x10^{-15}$ kg
ppm	-	parts per million
ppb	-	parts per billion
ppt	-	parts per trillion

A TOXICITY EQUIVALENCY FACTOR
PROCEDURE FOR ESTIMATING
2,3,7,8-TETRACHLORODIBENZO-P-DIOXIN
EQUIVALENTS IN MIXTURES OF
POLYCHLORINATED
DIBENZO-P-DIOXINS
AND POLYCHLORINATED
DIBENZOFURANS

2 INTRODUCTION

2.1 PURPOSE

This guidance is intended to document Department of Toxic Substances Control (DTSC) implementation of the I-TEF/89 method endorsed by the U.S. EPA. Other documents should be consulted for background information and detailed guidance for the development and use of Toxicity Equivalency Factors (TEFs) (DHS, 1986b; U.S. EPA, 1987, 1988a, 1989a; NATO/CCMS, 1988a, b).

2.2 APPLICATION

Use of the I-TEF/89 procedure as described in this document and as illustrated with examples in Table 4 and Appendices 1 through 3 ensures that consistent estimates of 2,3,7,8 - TCDD equivalents can be calculated for a mixture of PCDDs and PCDFs. Estimates of the concentration of 2,3,7,8-TCDD equivalents in soil, air and water can be derived using the I-TEF procedure for all state-lead sites, but issuance of this guidance does not affect exposure or risk assessments in progress or completed before the date of this publication.

2.3 LIMITATIONS

More toxicological and/or mechanistic research is necessary in order to provide an accurate assessment of risks posed by PCDDs and PCDFs. Thus, DTSC anticipates that the I-TEF/89 approach is an interim procedure, and the method will be updated periodically to reflect both gains in scientific knowledge and consistency with U.S. EPA procedures.

3 BACKGROUND

2,3,7,8-tetrachlorodibenzo-p-dioxin, commonly called "TCDD" or "dioxin," is the most potent animal carcinogen, reproductive and developmental toxin tested to date.

TCDD belongs to a family of organic chemicals which consist of two benzene rings connected to one another by two oxygens, as shown in Figure 1. Positions 1-4 and 6-9 on either of the benzene rings can be substituted with up to eight chlorines per molecule, to yield eight sub-classes with a total of 75 possible isomeric forms of the basic dioxin molecule. Chlorine substitutions at these positions can yield 2-mono, 10-di, 14-tri, 22-tetra, 14-penta, 10-hexa, 2-hepta, and 1-octa-chlorodibenzo-p-dioxin isomers (Table 1). Any of these are commonly referred to as "polychlorinated dibenzo-p-dioxins" (PCDDs).

A closely-related family of compounds, the polychlorinated dibenzofurans (PCDFs), consists of two benzene rings adjoined by a central furan ring, as shown in Figure 1. Substitution of chlorines at the 1-4 and/or 6-9 positions can yield up to a total of 135 possible isomers, including 4-mono, 16-di, 28-tri, 38-tetra, 28-penta, 16-hexa, 4-hepta, and 1-octa-dibenzofuran (Table 1). Any of these are commonly referred to as PCDF. None of the PCDFs have been tested for carcinogenic potential.

Initially, 2,3,7,8-TCDD was the only isomer of toxicologic concern, due to its presence as a manufacturing byproduct in the herbicide 2,4,5-trichlorophenoxyacetic acid. Additional concern was raised following two separate incidents: (1) Times Beach, Missouri, in 1971, when horses and dogs died as a result of application of TCDD-contaminated waste oil as a dust suppressant on dirt roads and in a horse arena, and (2) an industrial accident in Seveso, Italy, in 1976, in which a reaction vessel in a herbicide plant exploded and released an estimated 1.7 kg of TCDD over a town of 220,000 inhabitants.

Since then, PCDDs as well as PCDFs have been found to originate from other sources, such as: (1) technical grade pentachlorophenol used by numerous wood preservative treatment facilities; (2) fly ash from municipal garbage incinerators; and (3) other combustion sources. In many cases, the amount of other PCDDs and PCDFs released into the environment greatly exceed that of 2,3,7,8-TCDD. As a consequence, these compounds are ubiquitous in the environment, and are routinely detected as "background" contaminants in human adipose tissue. With the exception of 2,3,7,8-TCDD and a mixture of 1,2,3,6,7,8 and 1,2,3,7,8,9-hexachloro dibenzo-p-dioxins, the carcinogenic potential of PCDDs and PCDFs is largely unknown.

Various scientific groups have attempted to relate the toxic potency of PCDDs and PCDFs to that of 2,3,7,8-TCDD by use of information in the toxicity database for this class of compounds. The most recent effort is the "I-TEF/89" method developed by U.S. EPA in conjunction with scientists from other industrialized countries under the auspices of the North

Atlantic Treaty Organization's Committee on Challenges in Modern Society (NATO/CCMS). The I-TEF/89 method provides TEFs which can be used to calculate the concentrations of PCDDs and PCDFs in terms of an equipotent concentration of 2,3,7,8-TCDD.

4 TOXICITY OF PCDDs AND PCDFs

The Cal/EPA cancer potency factor (q_1^*) for 2,3,7,8-TCDD is 1.3 x 10^5 $(mg/kg/day)^{-1}$ based on animal studies in which TCDD was administered via the oral route. The Reference Dose (RfD) for TCDD for noncancer effects is 1.0 x 10^{-9} mg/kg/day based on studies in which TCDD was administered to animals by the oral route (U.S. EPA 1985a).

4.1 2,3,7,8-TCDD

The PCDD isomer having four chlorines, one each in the 2,3,7, and 8 position, is 2,3,7,8-tetrachloro dibenzo-p-dioxin, commonly referred to as "TCDD." 2,3,7,8-TCDD is the most potent animal carcinogen, reproductive/developmental toxin and teratogen known. The toxicity of 2,3,7,8-TCDD has been extensively studied, and the results are summarized in numerous criteria documents and journal reviews (Fishbein et al, 1987; Kimbrough et al, 1984; NATO/CCMS, 1988a, b; U.S. EPA, 1984, 1984a, 1985a, 1985b, 1989a).

4.1.1 Animal Carcinogenicity

2,3,7,8-TCDD was carcinogenic in male and female rats and mice (Kociba et al, 1978; NTP, 1980). Both studies were independently reviewed by the DTSC, Toxicology and Risk Assessment Section (TRAS) (DHS-TSCP, 1991). 2,3,7,8-TCDD was also carcinogenic in male hamsters (Rao et al., 1988).

- **Kociba et al. Study**

  Malignant tumors occurred in Sprague-Dawley rats receiving 2,3,7,8-TCDD in the feed at dose levels equivalent to 0.1, 0.01, 0.001, or 0 ug/kg body weight/day for two years. Four sites were involved:

  1. Squamous cell carcinoma of the hard palate/nasal turbinates in both males and females;
  2. Squamous cell carcinoma of the tongue in males;
  3. Squamous cell carcinoma of the lung in females; and
  4. Hepatocellular neoplastic nodules/carcinoma in females.

- **National Toxicology Program (NTP) Study**

  Malignant tumors occurred in both Osborne-Mendel rats and $B6C3F_1$ mice receiving 2,3,7,8-TCDD twice weekly by gavage in a corn oil:acetone vehicle (9:1). In rats and male mice, weekly dose levels were 0.5, 0.05, 0.01, or 0 ug/kg body weight/week, whereas weekly dose levels in female mice were 2.0, 0.2, 0.04, or 0 ug/kg body weight/week.

  In rats, the prevalence of thyroid follicular cell adenomas was significantly increased in males, with a non-significant trend for increase noted in females. In females, the prevalence of neoplastic nodules of the liver was significantly increased. No similar changes were observed in males.

  In mice, the prevalence of thyroid follicular cell adenomas in females was significantly increased, with no similar findings in males. Both males and females showed a significant increase in the prevalence of hepatocellular carcinomas.

- **Rao et al. Study**

  Malignant tumors occurred in male Syrian golden hamsters after intraperitoneal or subcutaneous injection with 2 or 6 doses, one dose every 4 weeks, of 50 or 100 ug/kg body weight of 2,3,7,8-TCDD. Twenty one percent of the animals receiving 6 doses of 100 ug/kg bodyweight developed a very rare tumor, squamous cell carcinoma of the facial skin, within 12-13 months of the beginning of the experiment. None of the controls or low dose animals had tumors. The induction of these very rare tumors by 2,3,7,8-TCDD in hamsters, the animal most resistant to 2,3,7,8-TCDD toxicity, argues for 2,3,7,8-TCDD having complete carcinogen activity, and not being solely a promoter.

- **Discussion**

  2,3,7,8-TCDD produced malignant tumors at a total of five different sites in the first two studies (Kociba et al., 1978, and NTP, 1980). Identical target organs were found in both rats and mice in the second study as well as in male and female rats of the first study. Particularly striking was the increased prevalence in both rats and mice, of thyroid follicular cell tumors which historically have a relatively low spontaneous rate for this tumor type.

The EPA classifies 2,3,7,8-TCDD as a probable human carcinogen (classification B2) and considers 2,3,7,8-TCDD to be the most potent chemical carcinogen and reproductive toxin yet evaluated by the EPA (U.S. EPA, 1989). There is adequate evidence from animal experiments that 2,3,7,8-TCDD functions as a complete carcinogen, not just as a promoter of carcinogenicity, (Rao et al., 1988; Bayard, 1989; Holder and Menzel, 1989). Support for the B2 classification includes observations that extremely low doses of 2,3,7,8-TCDD induce tumors, some of which are malignant, in multiple species of experimental animals, at multiple tumor sites, and that the spectrum of tumors induced by 2,3,7,8-TCDD in animals includes rare types of tumors.

4.1.2 Animal Developmental and Reproductive Toxicity

2,3,7,8-TCDD is the most potent reproductive toxin known, causing decreases in fertility, litter size, gestation survival, postnatal survival and postnatal body weight in rats administered relatively low levels of 2,3,7,8-TCDD in a three generation study (Murray et al., 1979). 2,3,7,8-TCDD is the most potent teratogenic and fetotoxic agent tested to date; these data have been reviewed in detail by U.S. EPA scientists in the EPA Health Assessment Document (U.S. EPA, 1985a), as well as in the dioxin Applied Action Level document (DHS-TSCP, 1990d and 1991).

4.1.3 Human Chronic Toxicity

Currently, there is no evidence that PCDDs pose a significant health risk to humans via environmental exposure. Numerous cases of human exposure including industrial accidents, use of dioxin-contaminated herbicides, and illegal disposal, have not clearly documented cancer or adverse reproductive effects in humans (Bond et al., 1989; Bertazzi et al., 1988; Hoffman et al., 1988; Mastroiacovo et al., 1988; Ott et al., 1987; Stehr-Green et al., 1988; Stockbauer et al., 1988; Webb et al., 1987).

The carcinogenic potency of 2,3,7,8-TCDD in animals, when compared on a molar basis, is greater than 50,000,000 times the potency for vinyl chloride, and 50 times the potency of aflatoxin B_1. Both of these are known human carcinogens (U.S. EPA, 1988d). Therefore, it is prudent to consider PCDDs and PCDFs as probable human carcinogens in the absence of definitive mechanistic or human epidemiological data to prove otherwise.

4.1.4 Other PCDDs AND PCDFs

The only other 2,3,7,8-substituted PCDD tested for carcinogenicity to date was a 1:2 mixture of 1,2,3,6,7,8- and 1,2,3,7,8,9-hexachlorodibenzo-p-dioxin, termed "HeCDD" (NTP, 1980). This mixture was carcinogenic in male and female rats and mice, producing malignant and benign liver cell cancer (IRIS, 1990).

In rats, there was a dose-related increase in hepatocellular neoplastic nodules and carcinomas in both sexes, with the increase achieving statistical significance in females. In mice also, there was a dose-related increase in hepatocellular adenomas and carcinomas, which reached significance in males. No other tumor types were noted in the IRIS database.

4.2 DOSE-RESPONSE - CANCER ENDPOINTS

- **2,3,7,8-TCDD**

The Carcinogen Assessment Group of U.S. EPA (CAG) used data of Kociba et al (1978) to calculate a "cancer potency factor" for 2,3,7,8-TCDD via low-dose extrapolation using the GLOBAL79 version of the linearized multistage model. Detailed discussions of the data sets utilized, the rationale for use, and values obtained are located in Section 11 and Appendix B of the Health Assessment Document for 2,3,7,8-TCDD (U.S. EPA, 1985a). The oral potency factor obtained was $1.5x10^5$ kg-day/mg.

- **Hexachlorodibenzo-p-Dioxin (HeCDD): Mixture of 1,2,3,6,7,8- and 1,2,3,7,8,9 Isomers, 1:2**

A mixture of two 2,3,7,8-substituted isomers of HeCDD was carcinogenic in rats and mice (NTP, 1980). As noted above, CAG used these results to calculate a cancer potency factor of $6.2x10^2$ kg-day/mg from these data (U.S. EPA 1990).

4.3 DOSE RESPONSE - DEVELOPMENTAL AND REPRODUCTIVE TOXICITY

2,3,7,8-TCDD is the most teratogenic agent tested to date. Numerous reviews are available for guidance (Fishbein, 1987; Silbergeld, 1987; U.S. EPA, 1984 and 1985a).

The Reference Dose (RfD) for developmental toxicity can be calculated from the lowest observed adverse effect level of 0.001 ug/kg/day in rats (Murray et al., 1979) in conjunction with a thousand-fold uncertainty factor. Based on these figures, the oral RfD is $1x10^{-9}$ mg/kg/day (U.S. EPA, 1985a).

4.4 DATA GAPS

It is unlikely due to problems of time and exspence that the extensive research conducted on 2,3,7,8-TCDD will be conducted on the remaining 209 PCDD and PCDF isomers. Therefore, much scientific research effort into the dioxin problem is focused upon mechanistic studies, but even these studies will take considerable time. Other relevant research would include testing the biological/toxicological response to complex environmental mixtures of PCDDs and PCDFs (U.S. EPA, 1989a).

The void of toxicity information for most of the 210 possible isomeric forms of PCDDs and PCDFs limits assessment of risk. The available database indicates that only those isomers having one chlorine each in the 2,3,7, and 8 positions are of toxicologic significance relative to 2,3,7,8-TCDD. This assumption enabled reduction of the number of isomers of concern from 210 to less than 20.

By default, the other isomers could be considered equipotent to 2,3,7,8-TCDD for risk assessment. However, potency data for non-cancer endpoints, such as acute, subchronic, reproductive, developmental, and immunotoxicity, as well as receptor binding or mechanistic data, suggest that the other 2,3,7,8-substituted isomers are moderately-to-substantially less potent than 2,3,7,8-TCDD. With 2,3,7,8-TCDD, however, cancer was the most sensitive endpoint of toxicity. Whether the carcinogenic potency of the other isomers is equal to or less than that of 2,3,7,8-TCDD remains unknown, except for HeCDD as discussed above.

5 USE OF THE TOXICITY EQUIVALENCY FACTOR (TEF) APPROACH FOR ESTIMATING TOXICITY OF A MIXTURE OF PCDDs AND PCDFs

The Department recommends use of the TEF approach to calculate 2,3,7,8-TCDD toxic equivalents. As several estimates of toxic equivalents exist, their origins and use is documented below:

5.1 THE TOXICITY EQUIVALENCY FACTOR (TEF) APPROACH

The TEF represents a ratio of the toxicity of a 2,3,7,8-substituted PCDD or PCDF isomer to that of 2,3,7,8-TCDD. With use of TEFs, the concentration of PCDD or PCDF isomers may be converted to equipotent concentrations of 2,3,7,8-TCDD. For example, the potency of a PCDF having a TEF of 0.05 and present in soil at a concentration of 100 ppm, would be equivalent of that of 2,3,7,8-TCDD at a concentration of 5 ppm.

5.1.1 California Department of Health Services TEF (DHS-TEF)

In the absence of a toxicity database, the California Air Resources Board requested in 1986 that the Department of Health Services (DHS) develop a method for assessment of cancer risks from PCDDs and PCDFs formed by combustion (DHS, 1986b). The data set used for development of DHS-TEFs consisted solely of the laboratory rodent bioassays with 2,3,7,8-TCDD and the hexachlorodibenzo-p-dioxin mixture. None of the remaining database for

PCDDs and PCDFs, such as acute, developmental, reproductive, immune system toxicity, or in vitro, mechanistic, or receptor binding studies, was considered for TEF development.

The DHS-TEF method (Table 2) assumed that:

- 2,3,7,8-substituted tetra-CDF, penta-CDDs, and penta-CDFs were equipotent to 2,3,7,8-TCDD,
- 2,3,7,8-substituted hexa- and hepta-CDDs and CDFs had 3% of the potency of 2,3,7,8-TCDD, and
- Octa-CDD, octa-CDF, and non-2,3,7,8-substituted CDDs and CDFs have zero potency relative to 2,3,7,8-TCDD.

The DHS-TEF approach was based on little data and is not recommended.

5.1.2 U.S. Environmental Protection Agency TEF (TEF/87)

Subsequently, the EPA adopted a TEF approach that differed significantly from that of DHS (U.S. EPA, 1987). The EPA approach (Table 2) utilized, in addition to the rodent bioassay data, data from acute, subchronic, developmental, immunotoxicity, reproductive, and in vitro toxicity studies as well as mechanistic investigations of PCDDs and PCDFs. Much of the data utilized in establishing the above TEFs (EPA, 1987) is believed to have little or no relevance to classical mechanisms of cancer induction. However, there is also considerable controversy as to the exact mechanism of cancer induction by 2,3,7,8-TCDD. 2,3,7,8-TCDD acts as a promoter of carcinogenicity and also as a complete carcinogen. Therefore, there may be some merit in considering toxicity other than cancer data in establishing TEFs for PCDDs and PCDFS. Also, it is often necessary to use TEFs not only to assess cancer risks but also to determine risks for other toxicities (such as developmental or reproductive toxicity) in humans exposed environmentally to mixtures of PCDDs and PCDFs.

Although the biochemical mechanisms leading to the toxic response resulting from exposure to PCDDs and PCDFs are not known in detail, there is considerable information now available, as summarized by EPA (U.S. EPA, 1989)... "experimental data have accumulated which suggest that an important role in the development of systemic toxicity resulting from exposure to (PCDDs and PCDFs) is played by an intracellular protein, the Ah receptor, the putative product of a gene locus designated Ah. This receptor binds halogenated polycyclic aromatic molecules, including PCDDs and PCDFs. It has been postulated that the Ah locus controls several pleiotropic responses: a limited, but widely expressed gene complex that includes the structural genes for aryl hydrocarbon hydroxylase expression, and, in a few organs, such as skin and thymus, a second gene complex regulating cell proliferation and differentiation...(Although) A recent review concludes that there are inconsistencies across species in the Ah receptor being the sole mechanism of toxicity of (PCDDs and PCDFs), the data suggest that the binding of these compounds to the receptor is in some way related to some of the biological effects seen in experimental animals.."

5.1.3 TEFs Developed by North Atlantic Treaty Organization/Committee on the Challenges of Modern Society (NATO/CCMS)

In 1989, a NATO Committee on the Challenges of Modern Society (NATO/CCMS) refined, extended and modified the EPA TEF/87 approach (NATO/CCMS, 1988). It should be noted that the NATO/CCMS dioxin committee was composed of scientists from participating countries, including Canada, Federal Republic of Germany, Italy, The Netherlands, Great Britain, and the United States. The U.S. EPA was instrumental in bringing this group together, and in obtaining an international consensus on the TEF approach. Like the EPA approach, the International TEFs (ITEF/88) developed by the NATO/CCMS committee (NATO/CCMS, 1988) utilized, in addition to the laboratory animal carcinogenicity data, data from acute, subchronic, developmental, immunotoxicity, reproductive, and in vitro toxicity studies as well as mechanistic investigations of PCDDs and PCDFs.

5.1.4 U.S. Environmental Protection Agency TEF (I-TEF/89)

In April 1989, the EPA determined that it would revise the EPA-TEFs/87, and adopted as agency interim policy the NATO/CCMS ITEF/88 method. The EPA I-TEF/89 represents the TEFs derived from the entire database (Table 3).

5.2 TECHNICAL GUIDANCE FOR USE OF TEFs

Use the I-TEF/89 procedure to calculate 2,3,7,8-TCDD Toxicity Equivalents as an estimate of exposure to mixtures of PCDDs and PCDFs. The I-TEF/89 values are shown in Table 3, and the use of the TEF procedure for estimating the exposure to mixtures of PCDDs and PCDFs is illustrated with an example in Table 4.

5.2.1 Selection of an Interim TEF Method for Use

Three factors were considered in recommending adoption of the I-TEF/89 values to replace the DHS-TEF approach:

- The DHS-TEF method was a major attempt to define the carcinogenic potency of PCDDs and PCDFs in the absence of data. However, acute, developmental, reproductive, in vitro, immunotoxicity, and mechanistic data were not utilized in derivation of TEF values in the DHS-TEF approach. As a result, the DHS-TEF method has received considerable criticism.

- More of the database was utilized in derivation of TEFs in the EPA TEF/87 approach. The NATO/CCMS method refined and expanded on EPA TEF/87 procedure. U.S. EPA adopted the I-TEF/88 method and endorsed it for Agency use. The I-TEF/89 approach represents the "state of the science," with TEFs derived from the entire database.

- Use of the I-TEF/89 procedure by DTSC would minimize conflicting risk assessments not only between DTSC and U.S. EPA, but also within DTSC itself.

5.2.2 Use of I-TEFs

The I-TEF/89 values from U.S. EPA are given in Table 3. These TEF values shall be used for calculation of PCDD and PCDF potency relative to that of 2,3,7,8-TCDD. The concentration of PCDD or PCDF is multiplied by the TEF to convert the PCDD or PCDF level to an equipotent concentration of 2,3,7,8-TCDD. The product is often referred to as a "TCDD equivalent."

6 USE OF I-TEFs FOR ESTIMATING HEALTH RISKS ASSOCIATED WITH EXPOSURE TO A MIXTURE OF PCDDs AND PCDFs

To estimate health risks associated with exposure to a mixture of PCDDs and PCDFs, use the concentration determined by the TEF procedure, and the Cancer Potency Factor and the RfD for 2,3,7,8-TCDD. The use of the TEF procedure for estimating the health risks associated with exposure to mixtures of PCDDs and PCDFs is illustrated with examples in Appendices 1-6.

6.1 CANCER RISK

The cancer potency factor listed by U.S. EPA for 2,3,7,8-TCDD (U.S. EPA, 1990) will be used to assess cancer risk posed by PCDDs and PCDFs. Such cancer risks are calculated by multiplying the average daily intake (in mg/kg/day) of 2,3,7,8-TCDD toxicity equivalents in the media by the cancer potency factor.

The oral cancer potency factor derived by U.S. EPA is $1.5x10^{5}$ kg-day/mg as listed on page B-18 of the Health Effects Assessment Summary Tables (U.S. EPA, 1991). No information was available in the IRIS database for 2,3,7,8-TCDD, presumably due to re-evaluation by U.S. EPA of the scientific basis and methods used in derivation of this cancer potency factor.

The cancer potency factor used for the risk assessment must be current. If an inhalation or dermal cancer potency factor is not available, it is appropriate to use the oral cancer potency factor, adjusted, if necessary, for incomplete absorption as described in Section 7.2.2.3 below. Guidance for this effort can be obtained from the TRAS.

6.2 NON-CANCER RISK

In estimating non-cancer hazards posed by a mixture of PCDDs and PCDFs, it is appropriate to use the Reference Dose (RfD) for 2,3,7,8-TCDD (1 pg/kg-day) derived by the U.S. EPA (1985a, 1989a). This RfD is currently based on reproductive/ developmental toxicity. It is important to ensure that the RfD employed is current at the time of writing of the risk assessment, since this value may be updated by either TRAS or U.S. EPA.

In estimating non-cancer hazards posed by inhalation of or dermal contact with an environmental medium containing a mixture of PCDDs and PCDFs, it is appropriate to adjust for absorption differences as discussed in Section 5.3 below. Guidance for this effort can be obtained from the TRAS.

6.3 ADMINISTERED vs ABSORBED DOSE

The current U.S. EPA oral cancer potency factor and the RfD tentatively proposed by TRAS for 2,3,7,8-TCDD are based upon administered dose and not absorbed dose. In the pivotal animal studies, 2,3,7,8-TCDD was administered in the feed.

Therefore, prior to correcting for incomplete absorption from an environmental medium of concern, it is necessary to adjust the current EPA 2,3,7,8-TCDD cancer potency factor or TRAS RfD by factoring in the ratio of absorbed dose to administered dose from the laboratory animal studies from which the cancer potency factor or the RfD were derived. Guidance for this effort can be obtained from the examples provided in Appendices 1-3.

6.4 EXAMPLES OF RISK CALCULATION USING TEFs

Appendices 1-3 provide detailed examples for the calculation of cancer risk according to three exposure scenarios:

- Ingestion of contaminated soil from such activities as mouthing behavior in children, hand-to-mouth activities such as smoking, and poor hygienic practices such as not washing hands before either preparing or eating food;

- Dermal absorption, that is, absorption of contaminants from soil adhering to skin, through the skin and into the body;

- Inhalation of wind-blown soil ("fugitive dust") with absorption of contaminants through the respiratory tract.

6.5 SUMMARY OF RISKS

Total Risk may be calculated by summation of individual risk from each exposure pathway, as shown in the examples in Appendices 1-6:

- **Total Cancer Risk**

Risk from Oral Ingestion (Appendix 1)	$= 1.8\text{x}10^{-7}$
Risk from Dermal Absorption (Appendix 2)	$= 6.0\text{x}10^{-8}$
Risk from Soil Inhalation (Appendix 3)	$= 8.9\text{x}10^{-9}$
Total	$= 2.5\text{x}10^{-7}$

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FIGURE 1

CHEMICAL STRUCTURES
POLYCHLORINATED DIBENZO-p-DIOXINS
POLYCHLORINATED DIBENZOFURANS

Polychlorinated dibenzo-p-dioxins (PCDDs)

Polychlorinated dibenzofurans (PCDFs)

Taken from page 4 of NATO/CCMS, 1988b.

TABLE 1

PCDD AND PCDF ISOMERS[a]
NUMBER OF CHLORINES PER SUBSTITUTION TYPE[b]

SUBSTITUTION TYPE	TOTAL NUMBER OF CHLORINES 1-Cl	2-Cl	3-Cl	4-Cl	5-Cl	6-Cl	7-Cl	8-Cl	Total
PCDDs									
One chlorine each in 2,3,7,8 positions	0	0	0	1	1	3	1	1	7
Others	2	10	14	21	13	7	1	0	68
								Subtotal	75
PCDFs									
One chlorine each in 2,3,7,8 positions	0	0	0	1	2	4	2	1	10
Others	4	16	28	37	26	12	2	0	125
								Subtotal	135

Total possible PCDDs and PCDFs = 210

Total non-2,3,7,8-CDDs and -CDFs = 193

Total 2,3,7,8-CDDs and -CDFs = 17

[a]PCDD = polychlorinated dibenzo-p-dioxin
PCDF = polychlorinated dibenzofuran

[b]From page 4 of USEPA, 1988b

TABLE 2

COMPARISON OF TOXICITY EQUIVALENCY FACTORS

Toxicity Equivalency Factor Scheme

COMPOUND[a]	DHS-TEF	EPA-TEF/87	I-TEF/89
Mono-, Di-, and Tri-CDDs	0	0	0
TCDD			
(2,3,7,8 chlorines)	1.0	1.0	1.0
(others)	0	0.01	0
PeCDD			
(2,3,7,8 chlorines)	1.0	0.5	0.5
(others)	0	0.005	0
HxCDD			
(2,3,7,8 chlorines)	0.03	0.04	0.1
(others)	0	0.0004	0
HpCDD			
(2,3,7,8 chlorines)	0.03	0.001	0.01
(others)	0	0.00001	0
OCDD	0	0	0.001
Mono-, Di-, and Tri- CDFs	0	0	0
TCDF			
(2,3,7,8 chlorines)	1.0	0.1	0.1
(others)	0	0.001	0
PeCDF			
(1,2,3,4,7,8 chlorines)	1.0	0.1	0.05
(2,3,4,7,8 chlorines)	1.0	0.1	0.5
(others)	0	0.001	0
HxCDF			
(2,3,7,8 chlorines)	0.03	0.01	0.1
(others)	0	0.0001	0
HpCDF			
(2,3,7,8 chlorines)	0.03	0.001	0.01
(others)	0	0.00001	0
OCDF	0	0	0.001

[a] Key: CDD = chlorinated dibenzo-p-dioxin; CDF = chlorinated dibenzofuran; TCDD = tetraCDD; PeCDD = pentaCDD; HxCDD = hexaCDD; HpCDD = heptaCDD; OCDD = octaCDD; TCDF = tetraCDF; PeCDF = pentaCDF; HxCDF = hexaCDF; HpCDF = heptaCDF; OCDF = octaCDF.

TABLE 3

1989 EPA INTERIM TOXICITY EQUIVALENCY FACTORS (I-TEFs/89)

CONGENER	TEF
POLYCHLORINATED DIBENZO-p-DIOXINS	
Tetra-CDD (chlorines in the 2,3,7,8 positions	1.0
Tetra-CDD (chlorines not in 2,3,7,8 positions)[a]	0
Penta-CDD (chlorines in the 2,3,7,8 positions)	0.5
Penta-CDD (chlorines not in 2,3,7,8 positions)[a]	0
Hexa-CDD (chlorines in the 2,3,7,8 positions)	0.1
Hexa-CDD (chlorines not in 2,3,7,8 positions)[a]	0
Hepta-CDD (chlorines in the 2,3,7,8 positions)	0.01
Hepta-CDD (chlorines not in 2,3,7,8 positions)[a]	0
Octa-CDD	0.001
POLYCHLORINATED DIBENZOFURANS	
Tetra-CDF (chlorines in the 2,3,7,8 positions)	0.1
Tetra-CDF (chlorines not in 2,3,7,8 positions)[a]	0
Penta-CDF (chlorines in the 2,3,4,7,8 positions)	0.5
Penta-CDF (chlorines in the 1,2,3,7,8 positions)	0.05
Penta-CDF (chlorines not in 2,3,7,8 positions)[a]	0
Hexa-CDF (chlorines in the 2,3,7,8 positions)	0.1
Hexa-CDF (chlorines not in 2,3,7,8 positions)[a]	0
Hepta-CDF (chlorines in the 2,3,7,8 positions)	0.01
Hepta-CDF (chlorines not in 2,3,7,8 positions)[a]	0
Octa-CDF	0.001

[a] Four chlorines must be in the 2,3,7,8-positions for toxicity.

TABLE 4

CALCULATION OF 2,3,7,8-TCCD TOXICITY EQUIVALENTS FROM PCDDs/PCDFs IN AN ENVIRONMENTAL SOIL SAMPLE[a]

Soil Sample

Congener	Toxic. Equiv. Factor	PCDD/F Concen. (pg/kg)	2,3,7,8-TCDD Toxic. Equiv. (I-TEFs/89) (pg/kg)
TCDDs	1	100	100
PeCDDS	0.5	200	100
HxCDDs	0.1	1,600	160
HpCDDs	0.01	1,900	19
OCDD	0.001	25,000	25
TOTAL PCDDs		28,800	404
TCDFs	0.1	400	40
PeCDFs			
1,2,3,7,8-	0.05	400	20
2,3,4,7,8-	0.5	400	200
HxCDFs	0.1	2,800	280
HpCDFs	0.01	1,600	16
OCDF	0.001	40,000	40
TOTAL PCDFs		45,600	596
TOTAL 2,3,7,8-TCDD TOXICITY EQUIVALENTS (I-TEFs/89) =			1,000

[a] Only those congeners that are chlorinated in the 2,3,7,8 positions are listed in the table.

APPENDIX 1

CANCER RISK FROM INGESTION OF CONTAMINATED SOIL

1. GASTROINTESTINAL ABSORPTION OF 2,3,7,8-TCDD

Scientists at U.S. EPA, TRAS, and contractors for TRAS-TSCP reviewed a number of studies in animals examining the gastrointestinal absorption of 2,3,7,8-TCDD from ingestion of contaminated soil, ingestion of 2,3,7,8-TCDD in the feed, and gastric intubation of 2,3,7,8-TCDD dissolved in organic materials such as corn oil. Results of these studies are critiqued elsewhere (pp. 120-126 of U.S. EPA, 1988a; Section 7 of U.S. EPA 1985a; Review No. 1, pp. 7-11, and Reviews No. 6-10 of TRAS, 1990d).

The data indicated that gastrointestinal absorption of 2,3,7,8-TCDD administered by intubation in corn oil was about 80%. Bioavailability of 2,3,7,8-TCDD administered in soil was 25% to 50% of that of 2,3,7,8-TCDD administered in corn oil, based on comparison of toxicologic endpoints used for derivation of TEFs by NATO/CCMS. Therefore, the reviewing scientists concluded that the amount of 2,3,7,8-TCDD absorbed from soil represented 20% to 40% of the dose of 2,3,7,8-TCDD ingested.

2. CORRECTION FOR ABSORPTION OF 2,3,7,8-TCDD BETWEEN DIFFERENT MEDIA

A bioavailability factor is calculated as the ratio of the bioavailability of 2,3,7,8-TCDD in the media of concern for each exposure route, divided by the bioavailability of 2,3,7,8-TCDD by the route used in the animal study from which the cancer potency factor was derived. The cancer potency factor for 2,3,7,8-TCDD was based on tumor prevalence in rats receiving 2,3,7,8-TCDD mixed into the feed. Gastrointestinal absorption of 2,3,7,8-TCDD from the feed was estimated to be 50% to 60% (Fries and Marrow, 1975); 50% will be used here. In comparison, the absorption of 2,3,7,8-TCDD ingested in soil was estimated to be 40%. Absorption differences such as these may need to be corrected for in calculation of soil ingestion risk.

Correction can be achieved by dividing the percentage of 2,3,7,8-TCDD absorbed from soil by that absorbed from the feed, to yield a "gastrointestinal absorption factor" (GAF):

$$\text{GAF} = \frac{\text{Percent absorbed from soil}}{\text{Percent absorbed from feed}} = \frac{40\%}{50\%} = 0.8$$

3. DAILY SOIL CONSUMPTION

For the purposes of this exercise only, daily soil consumption will be assumed to be 100 mg/day. Guidance for use of this or other values can be found elsewhere (Sedman, 1989; Calabrese et al., 1989; TRAS, 1990c; U.S. EPA, 1989a).

4. CANCER RISKS

Cancer hazards are assumed to have no threshold dose below which there is no risk. Much controversy surrounds this concern regarding certain animal carcinogens, including dioxins (U.S. EPA, 1988c and 1988d). For this example, however, no threshold will be assumed. The cancer potency factor in this exercise is used to estimate the risk of ANY exposure level, no matter how small. Specific guidance for nonthreshold effects as well as development and use of cancer potency ("slope") factors is given in Section 7.3 of the Human Health Evaluation Manual (U.S. EPA, 1989b), the Technical Standard for low-dose extrapolation (DHS-TSCP, 1990b), as well as numerous references provided by each of these documents.

In general, cancer risk may be estimated as follows:

$$\text{Risk} = \frac{\text{Exposure x Cancer Potency Factor x Bioavailability Factor}}{\text{Average Lifetime Body Weight}}$$

5. GENERAL ASSUMPTIONS FOR RISK CALCULATION

Lifetime exposure = 70 years
Average lifetime body weight = 70 kg
Cancer potency factor for 2,3,7,8-TCDD = $1.56\text{x}10^{5}$ kg-day/mg
(U.S. EPA, 1990)
Exposure = Soil ingestion x TCDD equivalents
Bioavailability factor = GAF

6. CALCULATION OF ESTIMATED RISK

$$\text{Risk} = \frac{\text{Soil Ingestion x TCDD Eq. x Cancer Potency Factor x GAF}}{\text{Body Weight}}$$

When:

Soil Consumption = 100 mg soil/day

TCDD Equivalents, from the example in Table 4, 1,000 pg TCDD Eq. per kg soil = $1x10^{-6}$ mg/kg = $1x10^{-12}$ mg/mg soil
Cancer Potency Factor = $1.56x10^{5}$ kg-day/mg
GAF = 0.8
Body Weight = 70 kg

Therefore:

$$\text{Risk} = \frac{100 \text{ mg/day} \times 1\text{x}10^{-12} \text{ mg/mg} \times 1.56\text{x}10^{5} \text{ kg-day/mg} \times 0.8}{70 \text{ kg}}$$

Risk = $1.8x10^{-7}$

APPENDIX 2

CANCER RISK FROM SKIN CONTACT WITH CONTAMINATED SOIL

1. DERMAL ABSORPTION OF 2,3,7,8-TCDD

Scientists at U.S. EPA, TRAS, and contractors for TRAS-TSCP reviewed a number of studies in animals examining the gastrointestinal absorption of 2,3,7,8-TCDD from ingestion of contaminated soil, ingestion of 2,3,7,8-TCDD in the feed, gastric intubation of 2,3,7,8-TCDD dissolved in organic materials such as corn oil, and dermal absorption. Results of these studies are critiqued elsewhere (pp. 120-126 of U.S. EPA, 1988; Section 7 of U.S. EPA 1985a; Review No. 1, pp. 7-11, and Reviews No. 6-10 of DHS-TSCP, 1990d).

The data indicated that dermal absorption of PCDDs from skin contact with soil is 0.9% in adults and 1.8% in children. The range of values cited was 0.07% to 3% of the administered dose. These results were derived by comparing various endpoints obtained after treatment by oral intubation vs skin contact with contaminated soil.

2. CORRECTION FOR ABSORPTION OF 2,3,7,8-TCDD BETWEEN DIFFERENT MEDIA

In general, a bioavailability factor is calculated as the ratio of the bioavailability of 2,3,7,8-TCDD in the media of concern for each exposure route, divided by the bioavailability of 2,3,7,8-TCDD in the vehicle used in the animal study from which the cancer potency factor was derived. The cancer potency factor for 2,3,7,8-TCDD was based on tumor prevalence in rats receiving 2,3,7,8-TCDD mixed into the feed. Gastrointestinal absorption of 2,3,7,8-TCDD from the feed was estimated to be 50% to 60% (Fries and Marrow, 1975); 50% will be used here. In comparison, the dermal absorption of soil-borne 2,3,7,8-TCDD in contact with skin was estimated to be 0.9% in adults and 1.8% in children, with values ranging from 0.07% to 3%.

Absorption differences such as these need to be corrected for in calculation of risk from dermal absorption of soil-borne chemicals. Correction can be achieved by dividing the maximal percentage of soil-borne 2,3,7,8-TCDD absorbed through the skin by that absorbed from the feed, to yield a "dermal absorption factor" (DAF):

$$DAF = \frac{\text{Percent absorbed from soil}}{\text{Percent absorbed from feed}} = \frac{3\%}{50\%} = 0.06$$

3. AMOUNT OF DAILY SKIN CONTACT WITH SOIL

For the purposes of this exercise only, the amount of soil coming in contact with, or adhering to, skin is assumed to be 450 mg/day. Specific guidance for use of this figure, or derivation of different values based on other age, activity, and time-weighted exposure scenarios, can be found elsewhere (Sedman, 1989; U.S. EPA, 1989b; DHS-TSCP, 1990c).

4. CANCER RISKS

Cancer hazards are assumed to have no threshold dose below which there is no risk. Much controversy surrounds this concern regarding certain animal carcinogens, including dioxins (U.S. EPA, 1988c and 1988d). For this example, however, no threshold will be assumed. The cancer potency factor in this exercise is used to estimate the risk of ANY exposure level, no matter how small. Specific guidance for nonthreshold effects as well as development and use of cancer potency ("slope") factors is given Section 7.3 of the Human Health Evaluation Manual (U.S. EPA, 1989b), the Technical Standard for low-dose extrapolation (DHS-TSCP, 1990b), as well as numerous references provided by each of these documents.

In general, cancer risk may be estimated as follows:

$$\text{Risk} = \frac{\text{Exposure x Cancer Potency Factor x Bioavailability Factor}}{\text{Average Lifetime Body Weight}}$$

5. GENERAL ASSUMPTIONS

Lifetime exposure = 70 years
Average lifetime body weight = 70 kg
Cancer potency factor for 2,3,7,8-TCDD = $1.56x10^{5}$ kg-day/mg
(U.S. EPA, 1990)
Exposure = daily skin/soil contact x TCDD equivalents
Bioavailability factor = DAF

6. CALCULATION OF ESTIMATED RISK

$$\text{Risk} = \frac{\text{Skin Soil Contact x TCDD Eq. x Cancer Potency Factor x DAF}}{\text{Body Weight}}$$

When:

Skin/Soil Contact = 450 mg soil/day
TCDD Equivalents, from the example in Table 4, 1,000 pg TCDD

Eq. per kg soil = $1\text{x}10^{-6}$ mg/kg = $1\text{x}10^{-12}$ mg/mg soil
Cancer Potency Factor = $1.56\text{x}10^{5}$ kg-day/mg
DAF = 0.06
Body Weight = 70 kg

Therefore:

$$\text{Risk} = \frac{450 \text{ mg/day x } 1\text{x}10^{-12} \text{ mg/mg x } 1.56\text{x}10^{5} \text{ kg-day/mg x } 0.06}{70 \text{ kg}}$$

$= 0.60\text{x}10^{-7}$
$= 6.0\text{x}10^{-8}$

APPENDIX 3

CANCER RISK FROM INHALATION OF CONTAMINATED SOIL

1. INHALATION ABSORPTION OF 2,3,7,8-TCDD

In the absence of data, absorption of TCDD is assumed to be 100% of the dose inhaled.

2. CORRECTION FOR ABSORPTION OF 2,3,7,8-TCDD BETWEEN DIFFERENT MEDIA.

In general, a bioavailability factor is calculated as the ratio of the bioavailability of 2,3,7,8-TCDD in the media of concern for each exposure route, divided by the bioavailability of 2,3,7,8-TCDD in the vehicle used in the animal study from which the cancer potency factor was derived. The cancer potency factor for 2,3,7,8-TCDD was based on tumor prevalence in rats receiving 2,3,7,8-TCDD mixed into the feed. Gastrointestinal absorption of 2,3,7,8-TCDD from the feed was estimated to be 50% to 60% (Fries and Marrow, 1975); 50% will be used here. In comparison, the absorption of 2,3,7,8-TCDD via inhalation of contaminated soil is assumed to be 100%.

These absorption differences must be corrected for in calculation of risk from inhalation of soil contaminated with PCDDs. Correction is achieved by dividing the percent absorbed by inhalation by that absorbed from feed, to yield an "inhalation absorption factor (IAF):"

$$IAF = \frac{\text{Percent of inhaled dose absorbed}}{\text{Percent absorbed from feed}} = \frac{100\%}{50\%} = 2.00$$

3. AMOUNT OF DUST INHALED PER DAY

For the purposes of this exercise only, the dust concentration in air is assumed to be 100 ug/m^3, and the respiration rate is assumed to be 20 m^3/day. Therefore, the quantity of dust inhaled per day is:

$$100\ ug/m^3 \times 20 m^3/day = 2{,}000\ ug/day = 2x10^{-3}\ mg/day$$

Specific guidance for derivation of different values based on other age, activity, and time-weighted exposure scenarios, can be found elsewhere (U.S. EPA, 1989a; DHS-TSCP, 1990a).

4. CANCER RISKS

Cancer hazards are assumed to have no threshold dose below which there is no risk. Much controversy surrounds this concern regarding certain animal carcinogens, including dioxins (U.S. EPA, 1988c and 1988d). For this example, however, no threshold will be assumed. The cancer potency factor in this exercise is used to estimate the risk of ANY exposure level, no matter how small. Specific guidance for nonthreshold effects as well as development and use of cancer potency ("slope") factors is given Section 7.3 of the Human Health Evaluation Manual (U.S. EPA, 1989b), the Technical Standard for low-dose extrapolation (DHS-TSCP, 1990b), as well as numerous references provided by each of these documents.

In general, cancer risk may be estimated as follows:

$$\text{Risk} = \frac{\text{Exposure x Cancer Potency Factor x Bioavailability Factor}}{\text{Average Lifetime Body Weight}}$$

5. GENERAL ASSUMPTIONS

Lifetime exposure = 70 years
Average lifetime body weight = 70 kg
Cancer potency factor for 2,3,7,8-TCDD = $1.56x10^{5}$ kg-day/mg
(U.S. EPA, 1990)
Exposure = Soil inhalation x TCDD equivalents
Bioavailability Factor = IAF

6. RISK FROM INHALATION OF SOIL CONTAINING PCDDs

$$\text{Risk} = \frac{\text{Soil Inhalation x TCDD Eq. x Cancer Potency Factor x IAF}}{\text{Body Weight}}$$

When:

Soil Inhalation = $2{,}0x10^{-3}$ mg/day
TCDD Equivalents, from the example in Table 4, 1,000 pg TCDD
Eq. per kg soil = $1x10^{-6}$ mg/kg = $1x10^{-12}$ mg/mg soil
Cancer Potency Factor = $1.56x10^{5}$ kg-day/mg
IAF = 2.00
Body Weight = 70 kg

Therefore:

$$\text{Risk} = \frac{2{,}000\text{x}10^{-3}\ \text{mg/day} \times 1\text{x}10^{-12}\ \text{mg/mg} \times 1.56\text{x}10^{5}\ \text{kg-day/mg} \times 2.00}{70\ \text{kg}}$$

$= 0.89\text{x}10^{-8}$

$= 8.9\text{x}10^{-9}$

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